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ARGONNE NATIONAL LABORATORY

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ENERGY REQUIREMENTS FOR MATERIALS USED IN VEHICLES CHARACTERIZED FOR THE TAPCUT PROJECT

Center for Transportation Research

Energy and Environmental Systems Division
ARGONNE NATIONAL LABORATORY

prepared for

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by

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prepared for

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Energy and Environmental Systems Division
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PREFACE

Charles L. Hudson, of Hudson Associates, was responsible for developing the method, data sources, critical assumptions, and energy estimates presented in this report. The TAPCUT project manager, Sarah J. LaBelle, of Argonne's Center for Transportation Research, directed the subcontracts under which Mr. Hudson worked and provided essential guidance during the course of the analysis. Margaret K. Singh, of the Center for Transportation Research, suggested that the detailed information Mr. Hudson had developed would be of value to others performing transportation energy analyses and was responsible for organizing and producing this report. Further inquiries about the contents of this volume should be directed to her.

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FOREWORD

Transportation directly consumes one quarter of the energy used in this country, with auto passenger travel accounting for half of the transport sector's energy use. Due to rising fuel prices and intermittent shortages, agencies of federal, state, and local governments have begun to introduce various strategies (combinations of policies and technologies) designed to conserve urban-transportation energy while maintaining a productive economy. The environmental consequences of many of these conservation strategies have not been adequately assessed. As a result, a technology assessment project sponsored by the U.S. Department of Energy, under the direction of David O. Moses, was initiated at Argonne National Laboratory in late 1979, with assistance from Brookhaven and Oak Ridge National Laboratories.

This project, Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT), had the stated goals of providing (1) a description of several alternative strategies promoting energy conservation in urban passenger transportation, (2) a better understanding of the environmental impacts of such strategies, and (3) identification of the constraints on the implementation of such strategies.

Two productive conservation strategies were designed to save energy in urban passenger transportation when substituted for policies now in place. A reference set of impact forecasts was then prepared for these two strategies. One conservation strategy stressed group travel, e.g., transit and carpooling, while the other promoted individual travel in private automobiles. The strategies were designed to cause minimal disruption of lifestyles and the economy while achieving reductions in the consumption of aggregate energy, especially that derived from petroleum.

Travel demand analysis was performed for each of three typical cities under policies now in place and forecast to continue, and under the alternative strategies, i.e., Group Travel Strategy and Individual Travel Strategy. Environmental impact analysis of the forecast travel demand under each strategy was city-specific and included estimation of air and water pollutant burdens along with their associated impacts on human health. Traffic safety impacts were also estimated. Socioeconomic impacts due to vehicle use and vehicle production were assessed. Impacts on physical environment, resources, health, and safety caused by vehicle and fuels production and infrastructure construction were also addressed. The final step was the overall comparison of policy-driven results to the results obtained under the In-Place Policy set.

Two economic and social-organization scenarios also were defined for this project; they differed in gross national product (GNP) growth rate, social organization, retail fuel price, total metropolitan population, average household income, environmental regulations, and types of fuel available for transportation. The two scenarios can be briefly distinguished as Scenario I, a wealthy economy with high technological success, and Scenario III, a relatively poor economy with low technological success. National urban and city specific forecasts of population and employment characteristics were prepared under each scenario.

The cities were selected using a factor-analysis technique that identified extreme cities along three dimensions relevant to transportation energy use. One dimension, called Megatown, identifies large cities with good transit systems. The second dimension, Sprawlburg, typifies newer, fast-growing, sprawl cities. The Slowtown dimension identifies midwestern industrial cities that are smaller in population than the other two. All metropolitan areas in the nation were related to these three dimensions; an expansion method was then developed in order to make national urban forecasts based on the detailed forecasts of the three typical cities selected to represent the three dimensions.

Automobile and transit vehicle characteristics were projected in detail under several sets of policy and scenario conditions. Three different sets of vehicles were used in the analysis: Set C, the expected technologies, was used for the In-Place Policy and Group Travel Strategy in both scenarios; Set A, designed as the best technology for both conservation and performance, was tested for the Individual Travel Strategy in one scenario; the third set, a modification of Set C, was tested in the other scenario under the Individual Travel Strategy. Vehicles were characterized by size class, engine type, fuel economy, emissions profile, purchase price, operating costs, materials composition, and (for personal vehicles) performance.

The city-specific land-use and demographic forecasts were organized for input to the Urban Transportation Policy Analysis Package. It incorporated state-of-the-art, household-based, disaggregate travel demand models for mode and destination choice with detailed specification of individual household auto ownership by automobile technology. Household characteristics from the base year in each city's travel survey were the basis of the forecasting approach to travel demand. Household records modified for each scenario, combined with the transportation level-of-service forecasts, which varied by policy, for the horizon years 1990 and 2000 drove the travel demand model. Transportation level-of-service parameters included detailed specifications of transit service and automobile characteristics. Both work and nonwork travel are separately forecast and reported for households in three income classes and for three locations within the urban area (center city, suburban, and exurban). Vehicle travel is also reported by area of occurrence for the atmospheric emissions and traffic safety analysis.

Results for the entire TAPCUT project have been presented in a final report entitled *Technology Assessment of Productive Conservation in Urban Transportation -- Final Report* (Argonne National Laboratory Report ANL/ES-130). This technical memorandum is one in a series of TAPCUT working papers that was selected for publication as a separate document to supplement the final report. The topic covered here is considered to be of interest to certain researchers/users who would not need to explore the full scope of TAPCUT. Conversely, the detail of presentation herein is inappropriate for the project's final report.

This report presents the method and data used to estimate the energy required by fuel type to produce each material used in the vehicles characterized for the TAPCUT project. Vehicle characterizations for TAPCUT are presented in two reports. The report *Vehicle Characterization for the TAPCUT Project: Performance and Cost* [by C. Hudson, E. Putnam, and M. Bernard, Argonne National Laboratory Report ANL/EES-TM-171 (Sept. 1981)] contains detailed descriptions of (1) the automobiles, vans, and transit vehicles used in the study and (2) the methods used to characterize the vehicles. In particular, vehicle weights and the distribution of materials used in bodies/chassis, engines, batteries, and motors are presented. The report *Vehicle Characterization for the TAPCUT Project: Materials, Energy, and Residuals of Manufacture* [by C. Hudson, E. Putnam, and R. Hildestad, Argonne National Laboratory Report ANL/EES-TM-188 (Nov. 1981)] presents estimates of the energy required by fuel type to produce each of the vehicles and explains the method used to derive these estimates. This current report is a supplement to the latter report. It explains in greater detail the method, data sources, and assumptions about material recycling rates, material import rates, production efficiency factors, and fuel source distributions used in estimating the energy required to produce the vehicle materials.

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ENERGY REQUIREMENTS FOR MATERIALS USED IN VEHICLES CHARACTERIZED FOR THE TAPCUT PROJECT

by

Charles L. Hudson

This report presents the method and data used to estimate the energy required to produce each material used in the vehicles characterized for Argonne's Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) project. The estimated energy requirements for material production are based both on reference data and on scenario-sensitive projections of material recycling rates, material import rates, production efficiency factors, and industrial fuel distributions. These data and projections are discussed below. On the basis of these projections and the material distributions and weights of specific vehicles, the energy required to produce the specific vehicles characterized for the TAPCUT project is generated. The energy required to produce each such vehicle is presented in Ref. 1.

1 REFERENCE DATA ON MATERIAL ENERGY CONTENT

Reference data pertaining to energy use in material extraction and processing (material energy content) are compiled by material type. Tables 1-9 present these data for iron and steel, aluminum, plastics, copper, rubber, lead, glass, zinc, and other materials. The beginning and end points of each analysis, the percentage of domestic vs. imported ore assumed in each reference, and the percentage of scrap vs. virgin material used in each analysis are reported. The tables also include an evaluation of the quality of each reference and report the year of analysis. Table 10 lists the fuel type distributions of energy required to extract and process various materials. As is evident from the tables, the estimates of energy required to produce each specific material often vary greatly.

2 ESTIMATED MATERIAL ENERGY CONTENT USED IN TAPCUT

2.1 AVERAGING OF REFERENCE DATA

Because the energy estimates provided in the reference data for specific materials often vary widely, an energy content value for each material had to be determined that could be supported by the majority of the references or the most comprehensive reference. Reference data were reconciled, where possible, by converting all data to a common measurement base and correcting for varying beginning and end points of the data analyses. For instance, some references began their analyses with the input of the material to the refinery and ended with mill output, whereas others began at the mine and ended at the production of a semifinished product. Reference data for a specific material also occasionally differed because they were products of studies made at different times and therefore reflected changing conditions. Plotting the adjusted data showed definite clusters of values for some materials. An average of these values was taken as the most likely energy content. Where no rational reconciliation of data was possible, judgment was used to assign a likely value. Usually, these assignments were based on data given by references that exhibited the most complete and understandable treatment of the subject.

Similar procedures were used to select the fuel distributions of the energy required to produce materials. In general, distributions by fuel type were, for a specific material, in closer agreement than estimates of the energy content of the material. Because material energy content by fuel type differs greatly for primary and recycling processes, energy requirements for both processes were estimated.

The average values determined for material energy content by fuel type were assumed to apply to energy requirements in 1975, the base year for this analysis. These values are reflected in the tables discussed below, which also incorporate material import rates and recycle rates into the estimates of the average energy required to produce each material.

2.2 SCENARIO-SENSITIVE FACTORS

The impacts of productive conservation strategies were examined in TAPCUT in the context of two socioeconomic scenarios: one (Scenario I) a wealthy economy with high technological success and the other (Scenario III) a relatively poor economy with low technological success. The energy required to produce materials is sensitive to such conditions. Different socioeconomic conditions lead to different material import rates, material recycle rates, production efficiencies, and industrial fuel use.

For example, the socioeconomic conditions and government policies in Scenario I were assumed to result in increased exports and initially relaxed environmental control on manufacturing in favor of energy efficiency gains. Under these conditions, production processes would improve greatly, and the improved processes would quickly replace outmoded ones. Imports of ores and fabricated materials would be reduced, and recycling would increase moderately. The use of purchased electricity for materials processing and plant operation would rise as it was substituted for petroleum where possible.

In Scenario III, little improvement was projected in the conservation of either energy or the environment. Lack of environmental control enforcement would result in some transitory increases in plant productivity. However, few new plants would be constructed and the faltering economy inherent in the scenario would require increasing material imports. The amount of recycling would also decrease. Little change in the existing distribution of industrial fuels was projected.

These characterizations of the scenarios are incorporated in the following material energy analysis by varying material import rates, production efficiency gains, recycle rates, and other factors. These factors and their implications are described more fully below.

2.2.1 Recycling and Import Assumptions

The material production energy that is expended in the United States depends in part on mining sites (U.S. or non-U.S.) and the efficiency of refining operations. In addition, it strongly depends on the degree of recycling (in general, recycled material expends about 20% or less of primary material energy) and the amount of semifabricated material purchased from foreign countries. For materials in the last category, no energy is credited to the United States, but the U.S. balance of payments may be adversely affected.

These four scenario-sensitive factors made it necessary to obtain or estimate, where possible and feasible, energy data for each of the following material production stages: (1) mining, (2) beneficiation (unless included in mining), (3) refining, (4) semifabrication, and (5) final fabrication. These stages may also be defined as (1) ore preparation, (2) manufacture of ingot/pig material or casting -- if poured directly from the furnace, (3) manufacture of sheet/wire/plate or other basic material forms purchased by the vehicle industry, and (4) forming/stamping/machining or other processing performed by the industry in the assembly of a vehicle.

In many cases, production energy estimates for each of the above were derived from the reference data and engineering judgment.

Tables 11-24 illustrate, for 14 of the major materials examined in this analysis, the assumptions made regarding import rates, recycling rates, and production efficiency improvements from 1975 to 2000 in the two TAPCUT scenarios. The rationale behind these assumptions for each specific material is also included. Table 25 quantifies the average energy required to produce a pound of each material using these assumptions regarding recycle, import, and efficiency rates. The equations used to derive the values in Table 25 are as follows:

$$E_P = (A_1\alpha_1 + A_2\alpha_2 + B\beta)VZ$$

$$E_R = D\theta WZ$$

$E_{MP} = C\phi VZ$*

$E_{MR} = C\phi WZ$*

$E_T = E_P + E_R + E_{MP} + E_{MR}$

where

E_P = Energy expenditure from the mine to a refined product,

E_R = Energy expenditure from recycled material collection to a refined product,

E_{MP} = Energy expenditure from the refined product of E_P to the semifabricated mill-end product,

E_{MR} = Energy expenditure from the refined product of E_R to the semifabricated mill-end product,

E_T = Total energy,

and where

A_1 = Mining or feedstock energy (Btu/lb),

α_1 = Fraction of ore or material that is mined or extracted in United States,

A_2 = Processing energy for other ores (Btu/lb),

α_2 = Fraction of other ore that is processed in United States,

B = Refining energy (Btu/lb),

β = Refining efficiency factor,

V = Fraction of semifabricated material that originates from virgin material,

Z = Fraction of semifabricated material that is U.S.-produced,

D = Scrap processing energy (Btu/lb),

*In E_{MP} and E_{MR}, Z = 1.00 if the material imported is primary material and not yet semifabricated.

θ = Scrap processing efficiency factor,

W = Fraction of semifabricated material that originates from recycled material,

C = Semifabrication energy (Btu/lb), and

ϕ = Semifabrication efficiency factor.

Table 26 contains the total energy required for 15 materials for which (1) little information is known about the energy content breakdown, (2) little or no recycling is possible, or (3) production is mostly in the United States. Efficiency improvements are included in the estimates as stated in the table.

The information shown for vehicle assembly is in Btu per pound of vehicle, not per pound of material. (The computer program used to calculate the energy required by fuel type to produce each vehicle incorrectly represented this vehicle fabrication energy per lb of vehicle as the total energy required for vehicle fabrication. This problem was found at the end of the study and thus was not corrected.)

2.2.2 Fuel Supply Assumptions

Energy distributions by fuel type are scenario-sensitive because the scenarios place varying emphases on the kinds of fuels used and also imply future major fuel-distribution changes. Estimates regarding the changes in percentage distribution of fuel types by scenario and year are shown in Table 27. These estimates are based on data obtained from the references as well as the fuel use projected for the scenarios (see Table 28 and Ref. 22). The rationale for the fuel source distributions for the various materials is presented in Table 27. Fuel distributions are shown for production materials from virgin material and from scrap where appropriate, as well as for semifabrication.

2.3 ENERGY PER POUND OF MATERIAL BY FUEL TYPE

Table 29 illustrates the results of the preceding process. For each material, the energy required to produce it under each scenario and in each analysis year is shown. The energy content reflects import rates, recycle rates, and efficiency improvements as well as different fuel distributions for production of the specific materials from virgin material and from scrap material and for semifabrication of the material. Because of cumulative percentage rounding, the total Btu-per-pound-of-material values in Table 29 differ slightly from the E_T values computed in Table 26. An adjustment in hundredths of a percent to reconcile the values would be meaningless because of the overall accuracy of the estimates, so the computed totals in Table 29 were allowed to stand as long as the differences with E_T values were insignificant.

3 DISCUSSION

3.1 ACCURACY OF ESTIMATES

According to the references that assessed the potential accuracy of their findings, ±30% or more potential error was common. Other references, particularly those on the aluminum production cycle, noted ranges varying about 20% from low to high values. The actual values depend on the process path. This work uses averages in all computations and therefore has, at best, confidence level ranges no less than those of the reference data.

The energy per pound of nickel as given by Ref. 5 appears high due to the preponderance of imports. Reference 17 gives the total energy from mine to primary metal as 72,000 Btu/lb. Therefore, assuming 90% imports, the U.S. energy credit should be in the region of 7,000-8,000 Btu/lb instead of the 44,900 Btu/lb given by Ref. 5. Because nickel may become an important constituent of battery vehicles, this disparity is important.

Zinc data are especially suspect because the few references found were too disparate to be reconciled. Engineering judgment was used in selecting an energy value for this study, but the value chosen is not supportable by empirical data. The weakness in zinc data affects the estimate of production energy for zinc chloride because the production energy of this compound was estimated from the atomic weights and production energies of its constituents.

Titanium data are weak for both total energy value and the related fuel distribution by type of fuel. The unusually large percentage of fuels listed in an "other" category by the references illustrates this fact. Lithium data are questionable because the proprietary nature of the lithium production process prevented an adequate analysis by the authors of the references.

Data on ceramics energy and residuals were based on high-fired porcelain insulator technology. It is not known how well these data approximate data for the silicon nitride materials that may be used in future Stirling and Brayton cycle engines.

According to Ref. 5, cobalt is thought to have energy and residuals values like those of copper. How well this approximation holds is unknown.

3.2 APPLICATION OF ESTIMATES IN TAPCUT

The information shown above for Scenarios I and III was also derived for a Scenario II, which assumed an environmentally sensitive society. However, this scenario was not studied in detail in TAPCUT and thus the estimates for it are not shown here. Reference 1 does contain results of the above process for Scenario II. In Ref. 1, Scenario II is referred to as Technology (Tech) Set B.

Also, early in the project each of the three scenarios was distinctly tied to a specific set of vehicles (Scenario I to Tech Set A, Scenario II to Tech Set B, and Scenario III to Tech Set C). Later in the analysis, it was decided to examine more than one technology set in each of two scenarios (I and III). Technology Set C vehicles were thus examined in Scenarios I and III, and a derivative of Tech Set C was also examined in Scenario III. The estimates made in this report for Scenario I were applied only to Tech Set A vehicles, which were used in only one of the travel policies of Scenario I (Individual Travel). The energy-per-pound-of-material estimates made in this report for Scenario III were applied whenever vehicles in Set C (or a derivative) were assumed, i.e., all travel policies in Scenario III and two travel policies (In Place and Group) in Scenario I. Readers attempting to use data in this report to recalculate the total energy to produce all vehicles under the different scenarios and policies shown in Ref. 22 thus must carefully select the technology set actually used in that reference.

Table 1 Summary of Reference Data on Iron and Steel Energy Content[a,b]

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Cold-rolled carbon steel	1974-75	Btu/lb	21,000	Mine	Fabricated (Fab.) sheet	NS[c]/NS/d/NS	None	4	Fair; sketchy methodology description refers directly to automotive materials.
Galvanized steel	1974-75	Btu/lb	21,500	Mine	Fab. sheet assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Aluminized steel	1974-75	Btu/lb	21,500	Mine	Fab. sheet assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Alloy steel	1974-75	Btu/lb	22,300	Mine	Fab. sheet assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Stainless steel	1974-75	Btu/lb	34,000	Mine	Fab. sheet assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Steel	~1978	10^9 Btu/10^6 lb	12,530	Mine	NS	18% natural, 54% taconite/ None/28/-	None	5	Fair; furnace end point assumed.
Primary	~1975	10^6 Btu/ton	12,500	Ore	Furnace output	NS/NS/ 18% computed/NS	Qualitative	3	Detailed.
Raw steel	1974	MMBtu/ton	9,665	Mine	Furnace output	NS	Qualitative	6	Detailed.
Steel	1974	10^6 Btu/ton	13,250	NS	NS	NS	34%, '74-'85 47%, '74-2000	7	Poor; furnace end point assumed -- no explicit methodology given.
Steel	1980	MBtu/in.^{3}	17,606	NS	Fab. form assumed	NS	None	8	Oriented for other purposes; table presentation only -- no assumptions given. Refer to auto use. Average steel density = 0.284 lb/in.^{3}
Primary carbon steel	~1971	kWh/ton	23,720	NS	Slab/pig assumed	NS	None	9	Fair; few assumptions given. Unit definition murky -- appears 3413 Btu/kWh is conversion used to obtain Btu thermal.
Cold-rolled carbon steel	~1971	kWh/ton	26,451	NS	Given[e]	NS	None	9	See above, Ref. 9.

Table 1 (Cont'd)

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Cold-rolled alloy steel	~1971	kWh/ton	27,765	NS	Given	NS	None	9	See above, Ref. 9.
Cold-rolled stainless steel	~1971	kWh/ton	39,489	NS	Given	NS	None	9	See above, Ref. 9.
Cast steel	~1975	10^6 Btu/ton	9,470	Ore assumed	Given	NS	Qualitative	3	Detailed.
Rolled steel	~1975	10^6 Btu/ton	24,743	Mine	Given	NS/NS/ 18% computed/NS	Qualitative	3	Detailed; avg. value given for rolling steel = 12,243 Btu/lb. This value added to primary steel value from Ref. 3 to obtain total fab.
Rolled steel	1971	10^6 Btu/ton	22,150	NS	Given	NS	20%, '73-'80 43%, '73-'90	10	Fair; reference has internal inconsistencies. Energy reduction projection computed from given use data.
Cast iron	1974-75	Btu/lb	10,300	Mine	Given	NS/NS/d/NS	None	4	See above, Ref. 4.
Nodular iron	1974-75	Btu/lb	14,050	Mine	Cast form assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Malleable iron	1974-75	Btu/lb	15,500	Mine	Cast form assumed	NS/NS/d/NS	None	4	See above, Ref. 4.
Iron	~1978	10^9 Btu/10^6 lb	10,860	Mine	NS	18% natural, 54% taconite, None/28%/-	None	5	See above, Ref. 5.

[a]As far as can be determined, all data either stated in or converted to a fossil fuel Btu basis.

[b]Iron ore --> iron ~ 3500 Btu/lb --> steel = 3760 Btu/lb: Refs. 2,3.

[c]NS = Not stated.

[d]Considered but not stated.

[e]The term "given" is used to indicate that the analysis end point is identical to the material form given by the reference nomenclature.

Table 2 Summary of Reference Data on Aluminum Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Primary-drawn	1974-75	Btu/lb	110,000	Mine	Drawn sections	NS[a]/NS/b/NS	None	4	Fair; sketchy methodology description. Refers directly to automotive end use.
Secondary-cast	1974-75	Btu/lb	10,000	Mine	Cast	NS/NS/b/NS	None	4	See above, Ref. 4.
Secondary-cast	~1975	10^6 Btu/ton	4,200	Scrap[b]	Cast	NS/NS/100%[c]/NS	Qualitative	3	Detailed.
Pure	~1975	10^6 Btu/ton	119,500	Ore	Furnace output	16.3/83.7/Assumed 0/ 100% Imp. alumina[c]	Qualitative	3	Detailed; uses 30% electrical generating efficiency. Includes energy of anode.
Pure	~1978	10^9 Btu/10^6 lb	244,000	Ore	Furnace output	100% bauxite	None	5	Fair. Furnace output assumed. Explicit methodology not stated.
Composite w/scrap	~1978	10^9 Btu/10^6 lb	58,570	Ore/scrap	Furnace output	4.25% bauxite/ 27/57.7/ 11.1% alumina	None	5	See above, Ref. 5.
Primary	1976	10^6 Btu/ton	93,900	Bauxite to alumina plant	Furnace output	NS/NS/Assumed 0/ NS	None	11	Environment oriented; for existing Hall-Heroult plants. Very difficult to extract detail. Mine energy not included. Anode fuel equivalent not included.
Primary	1976	10^6 Btu/ton	75,000	Bauxite to alumina plant	Furnace output	NS/NS/Assumed 0/ NS	None	11	Environment oriented; new Hall-Heroult plants. kWh-thermal conversion factor and mine energy not included. Anode fuel equivalent not included.
Primary	1976	10^6 Btu/ton kWh/ton	72,153	Bauxite to alumina plant	Furnace output	NS/NS/Assumed 0/ NS	None	11	Environment oriented; new Alcoa Aluminum plant. Mine energy not included. Anode fuel equivalent not included.
Primary	1976	10^6 Btu/ton	76,500	Bauxite to alumina plant	Furnace output	NS/NS/Assumed 0/ NS	None	11	Environment oriented; New T_1B_2 hall plant. Mine energy not included. Anode fuel equivalent not included.
Primary	1976	10^6 Btu/ton	80,000	Bauxite to alumina plant	Furnace output	NS/NS/Assumed 0/ NS	None	11	Environment oriented; new Toth plant. Mine energy not included. Anode fuel equivalent not included.

Table 2 (Cont'd)

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Rolled	1971	10^6 Btu/ton	104,000	NS	Given[d]	NS	12.5%, '75-'80 15.8%, '75-'85 22.6%, '75-'90	10	Poor; reference is internally inconsistant. Very high efficiency (34%) assigned to power generation.
Primary	1974	MMBtu/ton	87,875	Mine	Furnace assumed	NS	None	6	Detailed.
Die cast	1980	$MBtu/in.^3$	76,923	NS	Given	NS/NS/46%/NS	None	8	Oriented for other purposes; chart only. No supporting data. Refers directly to automotive use.
Primary	1974	10^6 Btu/ton	95,000	NS	Given	NS	24%, '74-'85 30%, '74-2000	7	Poor; little supportive methodology.
Primary	1978	10^6 Btu/ton	120,000	Bauxite	Given	Total Energy Estimate -- No Scrap	Qualitative	12	Good; data pt. is average of 139,000 and 101,000 Btu/lb. 30% elec. efficiency. Anode fuel equivalent apparently included. Total energy estimate.
Primary	1978	10^6 Btu/ton kWh/ton	130,289	Mine	Given	NS/NS/0.0/NS	None	13	Very explicit; Data pt. is average through an author-selected range of processes and process steps. Does not include fuel equivalent of anodes. Includes pollution control.
Primary	1978	10^6 Btu/ton kWh/ton	138,332	Mine	Given	NS/NS/0.0/NS	None	13	Very explicit; data pt. is average as noted above; includes fuel equivalent of anodes.
Secondary	1978	10^6 Btu/ton	4,250	Scrap	Furnace output	-/-/100%/-	None	13	Very explicit; data pt. is average of 2350 and 6100 Btu/lb.
Rolled	1975	kWh/ton	125,086	NS	Given	NS	None	9	Fair; definition of units and conversion factors used is murky. Appears 3413 Btu/kWh is used.
Cast	1975	kWh/ton	112,117	NS	Given	NS	None	9	Fair; see above, Ref. 9.

[a]NS - Not stated.

[b]Considered but not specified.

[c]The reference inferred 100% imported alumina but was not explicit.

[d]The term "given" indicates that the analysis end point is identical to the material form given by the reference nomenclature.

Table 3 Summary of Reference Data on Plastics Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Recycled Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Automotive	1974-75	Btu/lb	25,000	NS[a]	NS	Not considered	None	4	Fair; sketchy methodology description. Refers directly to automotive end use.
Polyethylene battery case	1978-79	10^9 Btu/10^6 lb	4,800	NS	NS	NS	None	5	Poor; no methodology description. Energy value may be order of magnitude low.
Average all thermoplastic	1971	10^6 kWh/ 10^3 metric tons	57,227	Plant input	Resin	NS	Yr 2000 = 55,000 Btu/lb	3	Detailed; feedstock energy value not included.
Low density polyethylene	1971	10^6 kWh/ 10^3 metric tons	76,260	Plant input	Resin	NS	Yr 2000 = 76,105 Btu/lb	3	Detailed; see above, Ref. 3.
High density polyethylene	1971	10^6 kWh/ 10^3 metric tons	39,644	Plant input	Resin	NS	Yr 2000 = 39,439 Btu/lb	3	Detailed; see above, Ref. 3.
Polyvinyl chloride	1971	10^6 kWh/ 10^3 metric tons	61,955	Plant input	Resin	NS	Yr 2000 = 61,916 Btu/lb	3	Detailed; see above, Ref. 3.
Polystyrene	1971	10^6 kWh/ 10^3 metric tons	30,771	Plant input	Resin	NS	Yr 2000 = 30,958 Btu/lb	3	Detailed; see above, Ref. 3.
Average all thermoplastic	1973	10^6 Btu/ton	47,800	Feedstock	Polymer	NS	7%, '74-'85 9.3%, '74-'90	10	Fair; energy to make feedstock included.
Low density polyethylene	1973	10^6 Btu/ton	46,750	Feedstock	Polymer	NS	8.5%, '74-'85 12.6%, '74-'90	10	Fair; see above, Ref. 10.
High density polyethylene	1973	10^6 Btu/ton	44,300	Feedstock	Polymer	NS	4.7%, '74-'85 9.3%, '74-'90	10	Fair; see above, Ref. 10.
Polyvinyl chloride	1973	10^6 Btu/ton	41,450	Feedstock	Polymer	NS	13.5%, '74-'85 13.5%, '74-'90	10	Fair; see above, Ref. 10.
Polystyrene	1973	10^6 Btu/ton	58,700	Feedstock	Polymer	NS	1.1%, '74-'85 1.7%, '74-'90	10	Fair; see above, Ref. 10.
Average all thermoplastic	1974	MMBtu/ton	47,619	Feedstock	Polymer	NS	None	6	Detailed; Ref. 6 used in Ref. 10 analysis.
Polyethlene battery case	1979	Btu/MWh	48,487	Feedstock	Case fabrication	NS	None	14	Detailed; 7.7 lb/MWh.
Thermoplastic polyester	1980	MBtu/in.^{3}	52,000	Feedstock	Resin inferred	None	None	8	Oriented for other purposes; chart only - no backup information. 36,000 Btu/lb process energy given.
Plastics	1975	10^6 Btu/ton	78,500	Feedstock	Resin inferred	None	13.4%, '74-'85 24.8%, '74-2000	7	Fair; little methodology description. 22,500 Btu/lb assigned to feedstock energy value.

[a]NS = Not stated.

Table 4 Summary of Reference Data on Copper Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Fabricated assumed	1974	Btu/lb	65,700	NS[a]	Fabricated assumed	NS	None	4	Fair; no supporting methodology. Refers directly to automotive use.
Primary assumed	1979	10^9 Btu/10^6 lb	43,970	Mine	Furnace output	66/9.3/10.6/ 14.1	None	5	Fair; little supporting methodology. Includes scrap and imports (∿54,212 w/o scrap or imports).
Primary	1975	10^6 Btu/ton	41,200	Mine	Furnace output	NS/NS/45/ 4.5	Qualitative	3	Detailed; concludes energy can be conserved but makes no projection (72,000 Btu/lb w/o scrap or imports)
Secondary	1975	10^6 Btu/ton	5,150	Furnace input	Furnace output	-/-/100/-	None	3	Detailed.
Rolled	1971	10^6 Btu/ton	31,500	NS	Given[b]	NS	None	10	Poor; Comparison with other processes only -- no supportive data.
Primary	1974	MMBtu/ton	57,905	Mine	Furnace output	NS	Qualitative	6	Detailed; concludes energy can be conserved but makes no projection.
Primary	1974	kWh/ton	46,417	NS	Furnace output	NS	None	9	Fair; no supporting methodology given. Conversion factor description murky.
Rolled	1974	kWh/ton	63,652	NS	Given	NS	None	9	Fair; see above, Ref. 9.
Wire	1974	kWh/ton	52,902	NS	Given	NS	None	9	Fair; see above, Ref. 9.
Rolled	1980	-	NS	Furnace input	Furnace output	NS/NS/0% inferred/ 0% inferred	25% @ some future year	15	Good for purpose; copper purity 99.9% -- not wire bar purity (99.99%), but good for many uses.

[a]NS = Not stated.

[b]The term "given" indicates that the analysis end point is identical to the material from given by the reference nomenclature.

Table 5 Summary of Reference Data on Rubber Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Recycled Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Auto rubber	1974	Btu/lb	36,900	NS[a]	NS	NS	None	4	Fair; no supporting methodology -- directed toward auto end use.
Styrene butadiene rubber	1975	10^6 Btu/ton	5,350	Plant input	Plant input	NS	None	3	Detailed; process fuel only -- "majority of energy consumed is contained in the material."
All rubber	1975	10^6 lbs (prod) 10^6 kWh (prod) 10^{12} Btu (prod)	14,916	Plant input assumed	Plant output assumed	NS	2.1%, '75-'85 6%, '75-'90	10	Poor; basis of calculation not stated. Inconsistent projections (1980 worse than 1975). Scrap-tire = 20% virgin.
Virgin styrene butadiene rubber	1974	MMBtu/ton	66,475	Feedstock	Product	0.0	None	6	Fair; little supportive data.
Average styrene butadiene rubber	1975	Btu/lb	6,000	Plant input	Plant output	0.0	–	10	Plant energy only.

[a]NS = Not stated.

Table 6 Summary of Reference Data on Lead Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Recycled Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Auto lead (Pb)	1974	Btu/lb	22,000	NS[a]	NS	NS	None	4	Fair; no supportive data.
Lead in batteries	1979	See remarks	6,258	NS	NS	51	None	5	Poor; Btu/lb derived by dividing total lead energy requirements (Table 12) by total lead wt. (Table 9).
Lead in batteries	1979	Btu/MWh	11,699	Mine	Product	56	None	14	Detailed; lead and lead in lead oxide = 28.9 lb/MWh (2000 cycles) based on C&D C75-15 battery. Fabrication energy = 3114 Btu/lb Pb.
Primary	1979	Btu/MWh	13,405	Mine	Primary	0	None	14	Detailed; based on 12.7 lb primary Pb in MWh (2000 cycle) battery.
Recovered	1979	Btu/MWh	4,772	Furnace input	Furnace output	100	None	14	Detailed; based on 16.2 lb recovered Pb in MWh battery.

[a]NS = Not stated.

Table 7 Summary of Reference Data on Glass Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Recycled Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Fabricated glass	1974	Btu/lb	13,000	NS[a]	NS	NS	None	4	Fair; no supporting methodology detail. Refers to auto product.
All glass	1975	10^{12} Btu/10^9 lb	8,088	Mine assumed	Product	NS	None	16	Good.
Container glass	1975	10^6 Btu/ton	5,500	Fab. plant	Product	NS	None	3	Detailed; excludes raw material preparation, product handling, and space conditioning.
Container glass	1975	10^6 Btu/ton	6,850	Raw material	Product	NS	None	3	Detailed; above data point plus manufacturing fuel equivalent energy consumption (p. 203, Table 3).
Container glass	1974	MMBtu/ton	9,105	Mine	Product	NS	None	6	Detailed.

[a]NS = Not stated.

Table 8 Summary of Reference Data on Zinc Energy Content

Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Fabricated	1974	Btu/lb	45,500	NS[a]	NS	NS	None	4	Fair; no supporting methodology. Refers to auto end use.
Primary assumed	1979	10^9 Btu/10^6 lb	5,980	Mine	Given[b]	42/13/39/6	None	5	Fair; no supporting detail.
Primary assumed	1979	10^9 Btu/10^6 lb	11,190	Mine	Given	100/0/0/0	None	5	Fair; all domestic production.
Die cast	1980	MBtu/in.^{3}	22,093	Mine assumed	Given	NS/NS/NS/5	None	8	Oriented for other purpose; density of zinc = 0.258 lb/in.^{3}
Primary	1975	kWh/ton	33,447	Mine assumed	Given	NS	None	9	Fair; no supporting methodology, energy units murky.
Rolled	1975	kWh/ton	39,591	Mine assumed	Given	NS	None	9	Fair; see above, Ref. 9.
Cast	1975	kWh/ton	43,857	Mine assumed	Given	NS	None	9	Fair; see above, Ref. 9.

[a]NS = Not stated.

[b]The term "given" indicates that the analysis end point is identical to the material form given by the reference nomenclature.

Table 9 Summary of Reference Data on Energy Content of Other Vehicle Materials

Material	Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Lithium	Metal assumed	1975	10^9 Btu/10^6 lb	197,800	Mine assumed	Metal	NS[a]	None	5	Fair.
Lithium sulfide	Battery product	1975	10^9 Btu/10^6 lb	63,000	Mine assumed	Product	100/NS/NS/NS	None	5	Fair; 30.2% lithium, 69.8% sulfur.
Lithium chloride	Battery product assumed	1975	10^9 Btu/10^6 lb	36,400	Mine assumed	Product	100/NS/NS/NS	None	5	Fair.
Potassium hydroxide	Product	1975	10^9 Btu/10^6 lb	4,680	NA	Product	NA[b]	None	5	Fair.
Silicon	Product	1975	10^9 Btu/10^6 lb	60,000	NS	Product	NS	None	5	Fair.
Silicon	Product	1975	10^6 Btu/ton	38,500	Mine	Product	NS	None	10	Detailed.
Cobalt	Product assumed	1975	10^9 Btu/10^6 lb	43,970	Mine assumed	Product	NS	None	5	Fair; ref. assumes similar to copper.
Ceramics	Product	1976	10^6 Btu/ton	40,000	Mine assumed	Product	NS	None	2	Detailed; engineering estimate. Assumes high temperature ceramics similar to hard porcelain.
Paint	Auto product	1974	Btu/lb	7,000	NA	Product	NA	None	4	Fair; no supporting detail. Auto oriented.
Sound Deadeners	Auto product	1974	Btu/lb	7,000	NA	Product	NA	None	4	See above, Ref. 4.
Sulfur	Product	1975	10^6 Btu/ton	443	Mine assumed	Product	NS	None	14	Detailed; average of frasch and smelter gas.
Sodium	Metal	1975	10^6 Btu/ton	46,000	Mine	Product	NS	None	17	Detailed; 1499 Btu/lb mining and salt purification.
Graphite	Product	1975	10^6 Btu/ton	80,000	Petroleum	Product	NS	None	17	See above, Ref. 17.
Zinc chloride	Product	1975	Btu/lb	18,579	Mine	Product	NA	NA	Eng. Estimate	Poor; 48% zinc, 52% chlorine on an atomic weight basis. Zinc = 33,447 Btu/lb, chlorine = 4,854 Btu/lb.

Table 9 (Cont'd)

Material	Reference Nomenclature	Analysis Year	Reference Measurement Units	Energy Content (Btu/lb)	Analysis Beginning Point	Analysis End Point	% Domestic Ore/ % Imported Ore/ % Scrap/% Other Source Material	Energy Reduction Projection	Ref. No.	Quality of Reference and Additional Comments
Titanium	U.S. sponge metal	1975	10^6 Btu/ton	179,260 (U.S.), 185,140 (Total)[c]	Mine	Product	0/100/0/0	None	17	Detailed; 100% ore in Australia.
Nickel	Electrolytic metal	1975	10^9 Btu/10^6 lb	45,400	Mine	Product	5/30% ore, 5% nickel sulfide/35% nickel concentrate/25	None	5	Fair.
Nickel		1975	10^6 Btu/ton	72,000	Mine	Product	NS/NS/NS/0	None	17	Detailed; 27,455 Btu/lb to obtain nickel concentrate.
Potassium chloride	Product	1975	10^9 Btu/10^6 lb	4,680	NA	Product	NA	None	5	Fair; assumed same as potassium hydroxide.
Molybdenum	-	-	-	None found	-	-	-	-	-	-
Boron Nitride	-	-	-	None found	-	-	-	-	-	

[a]NS = Not stated.

[b]NA = Not applicable.

[c]179,260 Btu/lb expended in the U.S.; 185,140 Btu/lb expended when energy for mining (outside the U.S.) is included.

Table 10 Summary of Reference Data on Fuel Distribution by Material[a]

Material	Coal (%)	Petroleum (%)	Natural Gas (%)	Liquefied Petroleum Gas (%)	Fuel Electricity (%)	Hydro-electricity (%)	Other (%)	Ref. Nos.	Remarks
Primary iron and steel	69.2	5.9	19.5	Negligible	5.5	-	-	2,3	Avg. of reference values.
Scrap to iron and steel	30.2/19.8	2.1/5.4	36.4/56.0	-	21.5/19.1	-	9.8/ inc. in coal	18	Cast iron foundary/cast steel foundary -- coal derived.
Primary aluminum	0.5	3.5	38	0.4	36.9	20.6	-	13	U.S. energy expenditure -- 1973 Bayer production of alumina required 6.3 x 10^6 Btu elec and 23.4 x 10^6 Btu/ton-aluminum gas or oil
Scrap to aluminum	9.9/3.6/ 7.8	4.6/17.3/ 8.8	66.7/60.5/ 64.6	-	19.1/8.6 15.6	-	0/10.0/ 5.0	18	Rolling and drawing aluminum/ Secondary nonferrous/Average scrap to rolled aluminum. Coal for drawing and rolling derived, includes "other."
Plastics	Negligible	26.4	66.3	-	7.2	-	-	14	For polyethylene; derivative fuel credit not included.
Primary copper	54.6	22.6	-	-	22.8	-	-	3	Assumes coke derived from coal.
Scrap to copper	3.5/3.6/ 3.5	20.3/17.3/ 18.7	43.9/60.5 52.9	-	24.9/8.6 16.1	-	7.6/10.0 8.8	18	Rolling and drawing Cu/ Secondary nonferrous/Average scrap to rolled drawn copper. Coal drawing and rolling copper derived, includes "other."
Virgin rubber	0.1	47.8	53.9	-	9.7	-	(11.5)	6	Other is a credit.
Primary lead	29.0	3.3	22.9	-	35.7	-	9.0	14	
Secondary lead	29.2	3	28.4	-	16.4	-	22.9	14	"Other" not defined.
All glass	2.0	17.5	68.0	-	10.0	-	1.2	19	1.3% not accounted for by reference.
Zinc	50.0	0.3	48.9	-	see remark	-	1.0	20	'72 census may have distributed electricity into its fuel components. '75 census says data are poor.

Table 10 (Cont'd)

Material	Coal (%)	Petroleum (%)	Natural Gas (%)	Liquefied Petroleum Gas (%)	Fuel Electricity (%)	Hydro-electricity (%)	Other (%)	Ref. Nos.	Remarks
Sodium	9.6	0.4	-	-	89	-	1.2	17	Steam assumed to come from coal.
Titanium	Negligible	7.4	2.4	-	66.5	-	24	17	Average of kroll and sodium reduction processes.
Electrolytic nickel	22.0	6.6	27.0	-	44.4	-	-	17	Steam assumed to be coal-derived.
Frasch sulfuric acid	-	-	94.4	-	0.5	-	5.1	14	
Recovered sulfur	0.0	0.0	0.0	-	0.0	-	0.0	14	100% exothermic reaction.
Sound deadeners	0.8	23.8	17.3	0.1	15.9	-	42.2	10	Assumes "sound deadeners" similar to pulp and paper industry. Steam assumed to be coal-derived. "Other" includes wood chips, bark, etc.
Paints	22.6	17.8	38.7	-	20.9	-	Inc. in coal	18	Coal-derived.
Cast aluminum	7.7	2.5	72.5	-	17.4	-	Inc. in coal	18	Coal-derived.
Ceramics	19.4/21.8/ 21.1	6.1/7.3/ 7.0	61.1/66.2/ 61.9	-	13.3/8.7/ 10.0	-	Inc. in coal	18	Electrical porcelain/Nonclay refactories/Average.
Tires	17.5	26.4	35.8	-	20.3	-	Inc. in coal	18	Coal-derived.
Carbon/graphite	-	19.6	39.6	-	40.9	-	Inc. in pet.	18	Petroleum-derived.
Vehicle fabrication	20.4	6.3	52.5	0.4	20.4	-	-	4,18	Ref. 4 for Chrysler, Ref. 18 for all vehicle manufacturing.

[a]Percentages may not add to 100% because of rounding or assumed "negligible" values.

Table 11 Energy Estimate Factors for Cold-Rolled Steel

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semi-fabricated Material Produced in U.S., Z
I/1975	3,760[b]	0.63	0.0	0.0	16,090[c]	1.0	0.72[d]	7,000[e]	1.0	0.28[d]	5,750[f]	1.0	1.0
1980		0.63				0.85	0.72		0.85	0.28		0.9	1.0
1990		0.63				0.60	0.66		0.8	0.34		0.7	1.0
2000		0.63				0.58	0.64		0.8	0.36		0.7	1.0
III/1975	3,760[b]	0.63	0.0	0.0	16,090[c]	1.0	0.72[d]	7,000[e]	1.0	0.28[d]	5,750[f]	1.0	1.0
1980		0.63				0.85	0.72		0.9	0.28		0.9	1.0
1990		0.63				0.87	0.75		0.95	0.25		0.95	0.9
2000		0.63				0.85	0.8		0.9	0.20		0.9	0.85

[a]Scenario I Rationale: Industry maintains export position. Initial relaxation of environmental controls helps rapid efficiency improvement but slows in later years when strict controls reinstituted. New refining plants drastically improve efficiency. Processing efficiency improvements not as great due to high technology level. Scrap recycling gains favor as energy costs climb.

Scenario III Rationale: Conservation ethic low. Little interest in expending funds for tighter environmental control. Major efficiency gains due to environmental control default. Little capital for more efficient plants. Productivity lessens to the point of requiring fabricated steel imports. Recycling struggling to hold rate and may drop due to lack of incentive and R&D funds. U.S. mines capable of supplying reduced U.S. foundry need. Imports could be more but reduced sales lessen need. Some efficiencies worsen because of plant aging and then improve slightly as some new plants come on line.

[b]Ref. 3.

[c]Refs. 5, 11 corrected for scrap.

[d]Ref. 5.

[e]Engineering estimate.

[f]Derived.

Table 12 Energy Estimate Factors for Stainless Steel

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	3,760[b]	0.63	0.0	0.0	26,090[c]	1.0	0.85	8,000[c]	1.0	0.15	7,750[c]	1.0	1.0
1980		0.63				0.85	0.85		0.85	0.15		0.9	1.0
1990		0.63				0.65	0.83		0.8	0.17		0.8	1.0
2000		0.63				0.63	0.81		0.8	0.19		0.8	1.0
III/1975	3,760[b]	0.63	0.0	0.0	26,090[c]	1.0	0.85	8,000[c]	1.0	0.15	7,750[c]	1.0	1.0
1980		0.63				0.9	0.85		0.9	0.15		0.9	1.0
1990		0.63				0.95	0.9		0.95	0.1		0.95	0.8
2000		0.63				0.9	0.9		0.9	0.1		0.9	0.75

[a]Scenario I Rationale: Generally the same as for cold-rolled steel (Table 11) except recycling technology not as well developed.

Scenario III Rationale: Generally the same as for cold-rolled steel -- but specialty nature of stainless and lack of productivity forces higher imports of fabricated material.

[b]Ref. 3.

[c]Appears to have higher processing energy than cold-rolled steel according to Refs. 4 and 9.

Table 13 Energy Estimate Factors for Cast Iron

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	3,500[b]	0.63	0.0	0.0	7,800[c]	1.0	0.72[d]	7,800[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.93	0.72		0.93	0.28		1.0	1.0
1990		0.63				0.83	0.66		0.83	0.34		1.0	1.0
2000		0.63				0.8	0.64		0.8	0.36		1.0	1.0
III/1975	3,500[b]	0.63	0.0	0.0	7,800[c]	1.0	0.72[d]	7,800[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.95	0.72		0.95	0.28		1.0	1.0
1990		0.63				0.95	0.75		0.95	0.25		1.0	0.9
2000		0.63				0.9	0.8		0.9	0.2		1.0	0.85

[a]Scenario I Rationale: Generally the same as for cold-rolled steel (Table 11) except furnace part of refining operation may have less chance for efficiency improvement.

Scenario III Rationale: Generally the same as for cold-rolled steel. Furnace part of refining operation may have less chance of efficiency gain.

[b]Ref. 3.

[c]Derived from Ref. 4 and corrected for scrap.

[d]Ref. 5.

[e]In semifabricated form at furnace output.

Table 14 Energy Estimate Factors for Nodular Iron

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semi-fabricated Material Produced in U.S., Z
I/1975	3,500[b]	0.63	0.0	0.0	11,525[c]	1.0	0.72[d]	11,525[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.93	0.72		0.93	0.28		1.0	1.0
1990		0.63				0.83	0.66		0.83	0.34		1.0	1.0
2000		0.63				0.8	0.64		0.8	0.36		1.0	1.0
III/1975	3,500[b]	0.63	0.0	0.0	11,525[c]	1.0	0.72[d]	11,525[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.95	0.72		0.95	0.28		1.0	1.0
1990		0.63				0.95	0.75		0.95	0.25		1.0	0.9
2000		0.63				0.9	0.8		0.9	0.2		1.0	0.85

[a]Scenario I Rationale: Generally the same as cold-rolled steel (Table 11) except furnace part of refining operation may have less chance for efficiency improvement.

Scenario III Rationale: See Scenario I rationale.

[b]Ref. 3.

[c]Derived from Ref. 4 and corrected for scrap.

[d]Ref. 5.

[e]In semifabricated form at furnace output.

Table 15 Energy Estimate Factors for Malleable Iron

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	3,500[b]	0.63	0.0	0.0	13,000[c]	1.0	0.72[d]	13,000[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.93	0.72		0.93	0.28		1.0	1.0
1990		0.63				0.83	0.66		0.83	0.34		1.0	1.0
2000		0.63				0.8	0.64		0.8	0.36		1.0	1.0
III/1975	3,500[b]	0.63	0.0	0.0	13,000[c]	1.0	0.72[d]	13,000[e]	1.0	0.28[d]	0.0[e]	1.0	1.0
1980		0.63				0.95	0.72		0.95	0.28		1.0	1.0
1990		0.63				0.95	0.75		0.95	0.25		1.0	0.9
2000		0.63				0.9	0.8		0.9	0.2		1.0	0.85

[a]Scenario I Rationale: Generally the same as for cold-rolled steel (Table 11) except furnace part of refining operation may have less chance for efficiency improvement.

Scenario III Rationale: See Scenario I rationale.

[b]Ref. 3.

[c]Derived from Ref. 4 and corrected for scrap.

[d]Ref. 5.

[e]In semifabricated form at furnace output.

Table 16 Energy Estimate Factors for Rolled/Wire Copper

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	27,250[b]	0.66[c]	0.0	0.0	30,500[d]	1.0	0.9[c]	5,200[e]	1.0	0.1[c]	15,000[f]	1.0	0.86[c]
1980		0.66				0.93	0.9		0.9	0.1		0.9	0.86
1990		0.66				0.82	0.83		0.8	0.17		0.85	0.9
2000		0.7				0.8	0.8		0.8	0.2		0.8	0.95
III/1975	27,250[b]	0.66[c]	0.0	0.0	30,500[d]	1.0	0.9[c]	5,200[e]	1.0	0.1[c]	15,000[f]	1.0	0.86[c]
1980		0.66				0.95	0.9		0.95	0.1		0.95	0.85
1990		0.60				0.9	0.9		0.9	0.1		0.9	0.75
2000		0.60				0.9	0.9		0.9	0.1		0.9	0.75

[a]Scenario I Rationale: Industry moves to become an exporter. Increased U.S. operations slightly increase energy/lb in 2000. Efficiency improvements occur rapidly as environmental controls are relaxed but taper off when reimposed. Recycling technology prospects improve as more electric vehicles with easily obtainable copper are scrapped.

Scenario III Rationale: See cold-rolled steel -- Scenario III for general tone (Table 11). Little incentive to recycle even though cost rises due to increasing petroleum costs. The metal may be cheaper from more stable foreign sources so imports rise. Rate of rise moderated by reduced demand.

[b]Beneficiation included -- Ref. 3.

[c]Ref. 5.

[d]Engineering estimate derived from average of Refs. 3, 6, and 7 corrected for scrap and finished metal imports. Tenuous estimate due to disparate source data.

[e]Engineering estimate.

[f]Ref. 9. Average of rolled and wire estimates less primary estimate.

Table 17 Energy Estimate Factors for Rolled/Drawn Aluminum

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Effi- ciency Factor, β	Virgin Material Fraction, V	Scrap- Processing Energy (Btu/lb), D	Scrap- Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifab- rication Energy (Btu/lb), C	Semifab- rication Efficiency Factor, ϕ	Fraction of Semi- fabricated Material Produced in U.S., Z
I/1975	5,450[a]	0.14[b,d]	19,000[c,d]	0.56[d]	95,550[d]	1.0	0.75	8,000[e]	1.0	0.25	20,000[e]	1.0	1.0
1980		0.14		0.56		0.9	0.54		0.95	0.46		0.95	1.0
1990		0.14		0.56		0.8	0.48[e]		0.85	0.52[e]		0.85	1.0
2000		0.20		0.65		0.8	0.42[e]		0.85	0.58[e]		0.85	1.0
III/1975	5,450[a]	0.14[b,d]	19,000[c,d]	0.56[c,d]	95,550[d]	1.0	0.75	8,000[e]	1.0	0.25	20,000[e]	1.0	1.0
1980		0.14		0.56		1.0	0.7		1.0	0.3		1.0	1.0
1990		0.14		0.56		0.9	0.65		0.95	0.35		0.95	1.0
2000		0.14		0.56		0.85	0.65		0.9	0.35		0.9	1.0

[a]Scenario I Rationale: Environmental control relaxation permits quick efficiency improvement which holds until new plants (Alcoa type) are in place. However, efficiency improvements are slowed by reimposition of strict environmental controls. Alumina from U.S. clay begins about 1995. Recycling first increases quickly and then slows as "easy" scrap diminishes.

Scenario III Rationale: See cold-rolled steel Scenario III for general tone (Table 11). Recycling interest low. Low investment capital scraps plans for Al clay development and new Alcoa type plants. Reduced demand counters reduced efficiency leaving import situation static.

[b]Bauxite mining.

[c]Alumina production.

[d]Ref. 12, Table 10 and p. 22 -- Average.

[e]Engineering estimate.

Table 18 Energy Estimate Factors for Cast Aluminum

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	0.0	-	0.0	-	0.0	-	0.0	8,000[b]	1.0	1.0[b]	2,000[c]	1.0	1.0
1980									0.95			0.95	1.0
1990									0.85			0.85	1.0
2000									0.85			0.85	1.0
III/1975	0.0	-	0.0	-	0.0	-	0.0	8,000[b]	1.0	1.0[b]	2,000[c]	1.0	1.0
1980									1.0			1.0	1.0
1990									0.95			0.95	1.0
2000									0.9			0.9	1.0

Scenario I Rationale: Efficiency improvement follows rolled/drawn case (Table 18). Most attention paid to primary processes. Environmental control (strict) reimposition slows efficiency improvement in 2000.

Scenario III Rationale: See cold-rolled steel (Table 11) and rolled/drawn aluminum (Table 17) Scenario III.

[b]100% scrap per Ref. 4.

[c]Engineering estimate.

Table 19 Energy Estimate Factors for Battery Lead

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semi-fabricated Material Produced in U.S., Z
I/1975	4,395[b]	0.95[b]	4,990[c]	1.0[c]	4,005[d]	1.0	0.44[e]	4,772[e]	1.0	0.56	3,114[e]	1.0	1.0
1980		0.95		1.0		1.0	0.44		1.0	0.56		1.0	1.0
1990		0.97		1.0		0.85	0.40		0.85	0.60		0.85	1.0
2000		0.97		1.0		0.85	0.40		0.85	0.60		0.85	1.0
III/1975	4,395[b]	0.95[b]	4,990[c]	1.0[c]	4,005[d]	1.0	0.44[e]	4,772[e]	1.0	0.56	3,114[e]	1.0	1.0
1980		0.95		1.0		1.0	0.44		1.0	0.56		1.0	1.0
1990		0.95		1.0		0.95	0.44		0.95	0.56		0.95	1.0
2000		0.95		1.0		0.9	0.44		0.9	0.56		0.9	1.0

[a]Scenario I Rationale: No important 75-80 change since Ref. 18 is circa 1978. Relaxation of environmental control permits marginal increase in efficiency in 1985. Recycle increases slowly because of mature 1978 technology and infrastructure. Interest in increasing U.S. ore mining picks up slightly. Reimposition of strict environmental controls after 1990 temporarily slows efficiency improvements. Maximum recycling attained 1990.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone. Recycling left up to industry which is satisfied to stay put. Reduced demand counters any need for import metal.

[b]Mine: Ref. 14.

[c]Smelting: Ref. 14.

[d]Refining and other: Ref. 14.

[e]Ref. 14.

Table 20 Energy Estimate Factors for Zinc

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	4,000[b]	0.42[c]	5,000[b]	0.55[d]	25,000[b]	1.0	0.94[e]	15,000[b]	1.0	0.06	15,000[b]	1.0	0.5
1980						1.0	0.94		1.0	0.06		1.0	0.5
1990						0.85	0.85		0.85	0.15		0.85	0.55
2000						0.80	0.83		0.80	0.17		0.80	0.6
III/1975	4,000[b]	0.42[c]	5,000[b]	0.55[d]	25,000[b]	1.0	0.94[e]	15,000[b]	1.0	0.06	15,000[b]	1.0	0.5
1980						1.0	0.94		1.0	0.06		1.0	0.5
1990						0.9	0.92		0.9	0.08		0.9	0.5
2000						0.9	0.9		0.9	0.1		0.9	0.5

[a]Scenario I Rationale: Little and disparate data forces liberal engineering estimates. 23,950 is close to Ref. 8 unsupported estimate of 22,093 Btu/lb. No change 75-80 since Ref. 8 is 1980. Relaxation of strict environmental control causes efficiency improvement in 1985. Slight increase in efficiency in 1990 is counterbalanced by industry interest in becoming a product exporter. Efficiency improvements slowed 1990-2000 because of reimposition of strict environmental control. Further industry interest in becoming an exporter counterbalances and raises U.S. energy.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone. Recycling not pushed. Industry left to its own devices. Reduced demand creates static import situation.

[b]Engineering estimate.

[c]Zinc oxide from domestic, Ref. 5.

[d]Proc. imp. ore, Ref. 5.

[e]Ref. 5.

Table 21 Energy Estimate Factors for Nickel

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	15,734[b]	0.06[c]	11,702[d]	0.53[c,e]	44,420	1.0	0.75[c]	10,000[f]	1.0	0.25[c]	10,000[f]	1.0	0.1
1980		0.06		0.53		0.95	0.75		0.95	0.25		0.95	0.1
1990		0.06		0.53		0.85	0.60		0.85	0.40		0.85	0.1
2000		0.06		0.53		0.8	0.50		0.8	0.5		0.8	0.1
III/1975	15,734[b]	0.06[c]	11,702[d]	0.53[c,e]	44,420	1.0	0.75[c]	10,000[f]	1.0	0.25[c]	10,000[f]	1.0	0.1
1980		0.06		0.53		0.95	0.75		0.95	0.25		0.95	0.1
1990		0.06		0.53		0.90	0.73		0.9	0.27		0.9	0.085
2000		0.06		0.53		0.9	0.72		0.9	0.28		0.9	0.085

[a]Scenario I Rationale: Export/import ratios do not change since U.S. is nickel poor. Efficiency improves due to relaxation of environmental controls to 1985 but slows later when strict controls are reimposed. Recycling technology gets most attention and improves markedly after 1985.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone. Recycling receives no interest. Demand is low, moderating rise in metal imports.

[b]Allocated mining Btu, Ref. 17.

[c]Derived from Ref. 5.

[d]Allocated beneficiation Btu, Ref. 17.

[e]If 47% import nickel concentrate, then U.S. must beneficiate 53% of all ore.

[f]Engineering estimate.

Table 22 Energy Estimate Factors for Titanium

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semi-fabricated Material Produced in U.S., Z
I/1975	5,880[b]	0.0[c]	–	–	179,260	1.0	1.0	10,000[d]	1.0	0.0	10,000[d]	1.0	1.0
1980						0.95	1.0		0.95	0.0		0.95	1.0
1990						0.85	0.95		0.85	0.05		0.85	1.0
2000						0.8	0.9		0.8	0.1		0.8	1.0
III/1975	5,880[b]	0.0[c]	–	–	179,260	1.0	1.0	10,000[d]	1.0	0.0	10,000[d]	1.0	1.0
1980						0.95	1.0		0.95	0.0		0.95	1.0
1990						0.95	1.0		0.95	0.0		0.95	0.9
2000						0.9	0.98		0.9	0.02		0.9	0.9

[a]Scenario I Rationale: 100% ore import thru time. Efficiency improves due to relaxation of environmental controls and then slows as strict controls are reimposed. No recycling technology until 1990 and then begins slow increase.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone. Technology advance for this difficult metal slow -- demand down. Some imports. Essentially no recycling.

[b]Allocated mining Btu, Ref. 17.

[c]10% import, Refs. 17, 21.

[d]Engineering estimate. Use in zinc-chloride battery not clear.

Table 23 Energy Estimate Factors for Cobalt

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Efficiency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifabrication Energy (Btu/lb), C	Semifabrication Efficiency Factor, ϕ	Fraction of Semifabricated Material Produced in U.S., Z
I/1975	27,250[b]	0.0[c]	0.0	0.0	30,500[b]	1.0	1.0	5,200[b]	1.0	0.0[d]	0.0[e]	1.0	1.0
1980						0.95	1.0		1.0	0.0		1.0	1.0
1990						0.85	1.0		1.0	0.0		1.0	1.0
2000						0.80	1.0		1.0	0.0		1.0	1.0
III/1975	27,250[b]	0.0[c]	0.0	0.0	30,500[b]	1.0	1.0	5,200[b]	1.0	0.0[d]	0.0[e]	1.0	1.0
1980						0.95	1.0		1.0	0.0		1.0	1.0
1990						0.9	1.0		1.0	0.0		1.0	1.0
2000						0.9	1.0		1.0	0.0		1.0	1.0

[a]Scenario I Rationale: Efficiency only possible improvement. All ore 100% imported. No recycling technology developed. Initial efficiency improvement due to relaxation of environmental control. Improvement slows in later years due to reimposition of strict controls.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone.

[b]Ref. 5 assumes cobalt and copper are similar.

[c]100% ore imports.

[d]No known recycling technology.

[e]Use of elemental material in battery assumed.

Table 24 Energy Estimate Factors for Rubber

Scenario/ Year[a]	Mining or Feedstock Energy (Btu/lb), A_1	Ore or Material Fraction Mined or Extracted in U.S., α_1	Processing Energy for Other Ores (Btu/lb), A_2	Fraction of Other Ores Processed in U.S., α_2	Refining Energy (Btu/lb), B	Refining Effi- ciency Factor, β	Virgin Material Fraction, V	Scrap-Processing Energy (Btu/lb), D	Scrap-Processing Efficiency Factor, θ	Recycled Material Fraction, W	Semifab- rication Energy (Btu/lb), C	Semifab- rication Efficiency Factor, ϕ	Fraction of Semi- fabricated Material Produced in U.S., Z
I/1975	61,125[b]	0.83[c]	0.0	0.0	5,350	1.0	0.8[d]	13,295[e]	1.0	0.2[d]	0.0[f]	1.0	1.0[g]
1980		0.78				0.95	0.75		0.95	0.25		1.0	1.0
1990		0.84				0.85	0.65		0.85	0.35		1.0	1.0
2000		0.87				0.8	0.6		0.8	0.4		1.0	1.0
III/1975	61,125[b]	0.83[c]	0.0	0.0	5,350	1.0	0.8[d]	13,295[e]	1.0	0.2[d]	0.0[f]	1.0	1.0
1980		0.79				0.95	0.75		0.95	0.25		1.0	1.0
1990		0.82				0.9	0.72		0.9	0.28		1.0	0.8
2000		0.85				0.9	0.7		0.9	0.3		1.0	0.8

[a]Scenario I Rationale: Recycling increases due to increasing feedstock energy cost. Manufacturing efficiency first improves due to relaxation of environmental controls then slows as strict controls are reimposed. Auto manufacturing industry will use U.S.-produced tires on all new equipment.

Scenario III Rationale: See cold-rolled steel Scenario III (Table 11) for general tone. Interest in recycling ebbs but high feedstock cost forces industry to recycle at somewhat less than optimum rate. Some auto manufacturers will buy foreign to avoid high U.S. cost.

[b]Estimated fuel content: 66,475 Btu/lb estimated total less 5,350 Btu/lb estimated by Ref. 3 as fabrication energy for tires.

[c]Reflects % U.S. petroleum-based feedstock from TAPCUT. (Ref. 22).

[d]Engineering estimate.

[e]Ref. 10 estimates 20% of virgin energy for recycled product.

[f]Assumes all U.S.-produced vehicles will have U.S.-produced tires.

[g]B and D include semifabrication to product.

Table 25 Material Energy Content by Material Production Stage (Btu/lb)

Material	Scenario/ Year	Primary Material to Semi-fabrication (E_P)	Recycled Material to Semi-fabrication (E_R)	Semi-fabrication from Primary Material (E_{MP})	Semi-fabrication from Recycled Material (E_{MR})	Total (E_T)
Cold-rolled Steel	I/1975	13,290	1,960	4,140	1,610	21,000
	1980	11,553	1,666	3,726	1,449	18,393
	1990	7,935	1,904	2,657	1,369	13,865
	2000	7,489	2,016	2,576	1,449	13,530
	III/1975	13,290	1,960	4,140	1,610	21,000
	1980	11,553	1,764	3,726	1,449	18,492
	1990	11,048	1,496	3,687	1,229	17,460
	2000	10,911	1,071	3,519	880	16,381
Stainless steel	I/1975	24,190	1,200	6,588	1,163	33,141
	1980	20,864	1,020	5,929	1,046	28,859
	1990	16,042	1,088	5,146	1,054	23,330
	2000	15,232	1,216	5,022	1,178	22,648
	III/1975	24,190	1,200	6,588	1,163	33,141
	1980	21,972	1,080	5,929	1,046	30,027
	1990	19,551	608	5,301	589	26,089
	2000	17,449	540	4,708	523	23,220
Cast iron	I/1975	7,204	2,184	0	0	9,388
	1980	6,810	2,031	0	0	8,841
	1990	5,728	2,201	0	0	7,929
	2000	5,405	2,246	0	0	7,651
	III/1975	7,204	2,184	0	0	9,388
	1980	6,923	2,075	0	0	8,998
	1990	6,490	1,667	0	0	8,157
	2000	6,273	1,193	0	0	7,466
Nodular iron	I/1975	9,886	3,227	0	0	13,113
	1980	9,305	3,001	0	0	12,306
	1990	7,769	3,252	0	0	11,021
	2000	7,312	3,319	0	0	10,631
	III/1975	9,886	3,227	0	0	13,113
	1980	9,471	3,066	0	0	12,537
	1990	8,879	2,463	0	0	11,342
	2000	8,553	1,763	0	0	10,316
Malleable iron	I/1975	10,948	3,640	0	0	14,588
	1980	10,292	3,385	0	0	13,677
	1990	8,577	3,669	0	0	12,246
	2000	8,067	3,744	0	0	11,811
	III/1975	10,948	3,640	0	0	14,588
	1980	10,480	3,458	0	0	13,938
	1990	9,825	2,779	0	0	12,604
	2000	9,455	1,989	0	0	11,444

Table 25 (Cont'd)

Material	Scenario/ Year	Primary Material to Semi-fabrication (E_P)	Recycled Material to Semi-fabrication (E_R)	Semi-fabrication from Primary Material (E_{MP})	Semi-fabrication from Recycled Material (E_{MR})	Total (E_T)
Rolled/ wire copper	I/1975	37,527	447	11,610	1,290	50,874
	1980	35,875	402	10,449	1,161	47,887
	1990	32,117	636	9,524	1,951	44,228
	2000	33,041	790	9,120	2,280	45,231
	III/1975	37,527	447	11,610	1,290	50,874
	1980	35,924	420	10,901	1,211	48,456
	1990	29,565	351	9,113	1,012	40,041
	2000	29,565	351	9,113	1,012	40,041
Rolled/ drawn aluminum	I/1975	80,215	2,000	15,000	5,000	102,215
	1980	52,595	3,496	10,260	8,740	75,091
	1990	42,165	3,536	8,160	8,840	62,701
	2000	37,750	3,944	7,140	9,860	58,694
	III/1975	80,215	2,000	15,000	5,000	102,215
	1980	74,867	2,400	14,000	6,000	97,267
	1990	63,309	2,660	12,350	6,650	84,969
	2000	60,203	2,528	11,700	6,300	80,731
Cast aluminum	I/1975	0	8,000	0	2,000	10,000
	1980	0	7,600	0	1,900	9,500
	1990	0	6,800	0	1,700	8,500
	2000	0	6,800	0	1,700	8,500
	III/1975	0	8,000	0	2,000	10,000
	1980	0	8,000	0	2,000	10,000
	1990	0	7,600	0	1,900	9,500
	2000	0	7,600	0	1,900	9,500
Battery lead	I/1975	5,795	2,672	1,370	1,744	11,581
	1980	5,795	2,672	1,370	1,744	11,581
	1990	5,063	2,434	1,059	1,588	10,144
	2000	5,063	2,434	1,059	1,588	10,144
	III/1975	5,795	2,672	1,370	1,744	11,581
	1980	5,795	2,672	1,370	1,744	11,581
	1990	5,707	2,539	1,302	1,657	11,205
	2000	5,619	2,405	1,233	1,569	10,826
Zinc	I/1975	13,832	450	15,000	900	30,182
	1980	13,832	450	15,000	900	30,182
	1990	12,005	1,052	11,922	2,104	27,083
	2000	12,166	1,224	12,000	2,040	27,430
	III/1975	13,832	450	15,000	900	30,182
	1980	13,832	450	15,000	900	30,182
	1990	12,388	542	12,240	1,080	26,250
	2000	12,119	675	12,150	1,350	26,294

Table 25 (Cont'd)

Material	Scenario/ Year	Primary Material to Semi-fabrication (E_P)	Recycled Material to Semi-fabrication (E_R)	Semi-fabrication from Primary Material (E_{MP})	Semi-fabrication from Recycled Material (E_{MR})	Total (E_T)
Nickel	I/1975	3,867	2,500	10,000	2,500	18,867
	1980	3,701	2,375	9,500	2,375	17,951
	1990	2,694	3,400	8,500	3,400	17,994
	2000	2,134	4,000	8,000	4,000	18,134
	III/1975	3,867	2,500	10,000	2,500	18,867
	1980	3,701	2,375	9,500	2,375	17,951
	1990	2,632	2,187	9,000	2,430	16,249
	2000	2,596	2,268	9,000	2,520	16,384
Titanium	I/1975	179,260	0	10,000	0	189,260
	1980	170,297	0	9,500	0	179,797
	1990	144,752	425	8,075	425	153,677
	2000	129,067	800	7,200	800	137,867
	III/1975	179,260	0	10,000	0	189,260
	1980	170,297	0	9,500	0	179,797
	1990	153,267	0	8,550	0	161,817
	2000	142,297	162	7,938	162	150,559
Cobalt	I/1975	30,500	0	0	0	30,500
	1980	29,000	0	0	0	29,000
	1990	25,950	0	0	0	25,950
	2000	24,400	0	0	0	24,400
	III/1975	30,500	0	0	0	30,500
	1980	28,980	0	0	0	28,980
	1990	26,340	0	0	0	26,340
	2000	26,340	0	0	0	26,340
Tire rubber	I/1975	44,867	2,659	0	0	47,526
	1980	39,570	3,158	0	0	42,728
	1990	36,330	3,955	0	0	40,285
	2000	34,475	4,254	0	0	38,729
	III/1975	44,867	2,659	0	0	47,526
	1980	40,028	3,158	0	0	43,186
	1990	31,644	2,680	0	0	34,324
	2000	31,792	2,872	0	0	34,664

Table 26 Production Energy of Materials for which Little is Known about Energy Content Breakdown, Little or No Recycling is Possible, or Mostly U.S. Production is Estimated (Btu/lb)

	Scenario I					Scenario III				
Material[a]	1975	1980	1990	2000	Rationale	1975	1980	1990	2000	Rationale
Plastics[b]	53,880	49,680	48,240	48,120	c	53,880	51,540	50,820	51,000	d
Glass[e]	10,000	9,800	9,300	9,000	10% Imp.	10,000	9,880	9,630	9,500	5% Imp.
Lithium[f]	197,800	197,800	178,000	168,150	15% Imp. begins 1985	197,800	197,800	189,890	181,970	8% Imp. begins 1985
Lithium sulfide in batteries[f]	63,000	63,000	56,700	53,550	15% Imp. begins 1985	63,000	63,000	60,480	57,960	8% Imp. begins 1985
Lithium chloride in batteries[f]	36,400	36,400	32,760	30,940	15% Imp. begins 1985	36,400	36,400	34,940	33,490	8% Imp. begins 1985
Potassium hydroxide[g]	4,680	4,590	4,330	4,210	9% Imp.	4,680	4,610	4,470	4,400	6% Imp.
Silicon[h]	49,300	46,850	41,900	39,500	20% Imp.	49,300	48,070	45,600	44,370	10% Imp.
Ceramics[i]	40,000	40,000	40,000	40,000	No change	40,000	40,000	40,000	40,000	No change
Paint[j]	7,000	7,000	6,500	6,500	7% Imp. begins 1980	7,000	7,000	6,810	6,720	4% Imp. begins 1980
Sound deadeners[j]	7,000	7,000	6,500	6,500	7% Imp. begins 1980	7,000	7,000	6,810	6,720	4% Imp. begins 1980
Sulfur[k]	443	443	443	443	No change	443	443	443	443	No change
Sodium[l]	46,000	46,000	42,000	41,400	9% Imp. begins 1980	46,000	46,000	44,160	43,240	6% Imp. begins 1980
Graphite[m]	1,000	1,000	1,000	1,000	No change	1,000	1,000	1,000	1,000	No change
Zinc chloride[n]	18,600	18,600	18,600	18,600	No change	18,600	18,600	18,600	18,600	No change
Sulfuric acid[o]	20	20	20	20	No change	20	20	20	20	No change
Vehicle fab.[j]	6,885	6,600	6,300	6,200	10% Imp.	6,885	6,780	6,580	6,470	6% Imp.

[a] No data were available for molybdenum or boron nitride.

[b] 36,000 Btu/lb feedstock energy per Ref. 8. Efficiency improvement applied to process energy.

[c] 30% efficiency improvement by 2000 in process energy (24,000 Btu/lb 1975) adjusted by % domestic feedstock -- see rubber.

[d] 15% efficiency improvement by 2000 in process energy (24,000 Btu/lb 1975) adjusted by % domestic feedstock -- see rubber.

[e] Established technology - minimal efficiency improvement.

[f] Lithium energy details proprietary (Ref. 17). New technology, little efficiency improvement.

[g] Established technology - little efficiency improvement.

[h] 1975 average of Refs. 5 and 17. Little known about processing energy.

[i] Uses high temperature porcelain as surrogate for high temperature ceramics. No efficiency improvement taken to reflect late-year new high-temperature technology.

[j] Established technology. Most efficiency improvements from temporary relaxation of environmental controls.

[k] Reaction mostly exothermic. Negligible benefits from efficiency improvement.

[l] New technology for batteries. Little chance for efficiency improvement.

[m] Mostly feedstock energy. 90% imported (Ref. 21); U.S. process energy unknown. Assumed 1000 Btu/lb.

[n] Tenuous engineering estimate for 1975 energy does not warrant efficiency projections.

[o] Btu impact small; scenario breakdown meaningless.

Table 27 Fuel Distributions by Material, Scenario, and Year (%)[a]

		Primary and Recycle Material through Refining						Semifabrication[b]			
Material	Scenario/ Year	Coal	Petro- leum	Gas	Purchased Elec- tricity	Hydro- elec- tricity	Other	Coal	Gas	Purchased Elec- tricity	Rationale
Cold-Rolled Steel/Stainless Steel/Iron	I/1975	69.2	5.9	19.5	5.5	–	–	0	0	100	Assumes coal/gas distribution for refined semifabrication processing is same as primary distribution (all materials). Coal use increases rapidly during 1980-85 as environmental restrictions ease. Continues to increase as control technology advances. Petroleum reaches lower limit in '85 but natural gas use continues to decline. Purchased electricity is mainly plant and machine tool energy. Slight increase in year 2000. New U.S. discoveries of natural gas support moderate decline.
	1980	69.2	5.9	19.5	5.5	–	–	0	0	100	
	1990	75.2	2.9	16.4	5.5	–	–	0	0	100	
	1000	79.2	1.9	12.4	6.5	–	–	0	0	100	
	III/1975	69.2	5.9	19.5	5.5	–	–	0	0	100	Coal use increases slowly because of limited investment resource in new mining technology. Oil reduced some because of high cost. Natural gas imports rise but percentage reduced slowly. Most changes occur in purchased electricity -- little effort made to convert operations from 1975 percentage since few new plants are built.
	1980	69.2	5.9	19.5	5.5	–	–	0	0	100	
	1990	72.0	4.7	17.8	5.5	–	–	0	0	100	
	1000	75.0	4.5	15.0	5.5	–	–	0	0	100	
Scrap to iron	I/1975	30.2	2.1	36.4	21.5	–	9.8	0	0	0[c]	See cold-rolled steel for general tone. Conversion to electric furnaces increases as new plants are constructed. Oil at a minimum. Gas-fired furnaces converted to fluidized-bed coal.
	1980	30.2	2.1	36.4	21.5	–	9.8	0	0	0	
	1990	35.0	2.0	31.0	23.0	–	9.0	0	0	0	
	2000	39.0	2.0	24.0	26.0	–	9.0	0	0	0	
	III/1975	30.2	2.1	36.4	21.5	–	9.8	0	0	0	See cold-rolled steel for general tone. Little happens because of investment capital lack. Changes to coal made where easily accomplished to reduce use of petroleum/natural gas. Little pressure from recycling groups because of low interest and fragmented approach.
	1980	30.2	2.1	36.4	21.5	–	9.8	0	0	0	
	1990	32.0	2.0	34.7	21.5	–	9.8	0	0	0	
	2000	34.0	2.0	32.2	22.0	–	9.8	0	0	0	
Scrap to steel	I/1975	19.8	5.4	56.0	19.1	–	–	0	0	100	See cold-rolled steel and scrap to iron.
	1980	19.8	5.1	56.0	19.1	–	–	0	0	100	
	1990	25.0	3.0	50.0	22.0	–	–	0	0	100	
	2000	29.0	3.0	43.4	24.6	–	–	0	0	100	
	III/1975	19.8	5.4	56.0	19.1	–	–	0	0	100	See cold-rolled steel and scrap to iron.
	1980	19.8	5.4	56.0	19.1	–	–	0	0	100	
	1990	21.5	4.5	55.0	19.1	–	–	0	0	100	
	2000	24.5	4.0	52.0	19.1	–	–	0	0	100	

Table 27 (Cont'd)

Material	Scenario/ Year	Primary and Recycle Material through Refining: Coal	Petro- leum	Gas	Purchased Elec- tricity	Hydro- elec- tricity	Other	Semifabrication[b]: Coal	Gas	Purchased Elec- tricity	Rationale
Aluminum	I/1975	0.5	3.5	38.4	36.9	20.6	-	10.0	40.0	50.0	See cold-rolled steel for general tone. Hydro-electricity has a fixed Btu output, therefore, its percentage drops as volume of aluminum required is reduced. Most natural gas is used for alumina production and its use decreases slowly as fluidized coal technology takes hold.
	1980	0.75	3.5	38.2	36.9	20.6	-	10.0	40.0	50.0	
	1990	2.0	3.0	37.5	39.5	18.0	-	20.0	30.0	50.0	
	2000	4.0	2.5	36.0	42.5	15.0	-	25.0	25.0	50.0	
	III/1975	0.5	3.5	38.4	36.9	20.6	-	10.0	40.0	50.0	See cold-rolled steel for general tone. Hydro-electricity still has a fixed Btu output but percentage drop is not as steep because vehicle production may be less. Lack of capital investment funds places even higher load on natural gas.
	1980	0.7	3.5	38.3	36.9	20.6	-	11.0	39.0	50.0	
	1990	1.3	2.7	38.5	39.5	18.0	-	12.0	38.0	50.0	
	2000	1.6	2.5	38.4	40.5	17.0	-	15.0	35.0	50.0	
Scrap to aluminum	I/1975	7.8	8.8	64.6	15.6	-	5.0	0	0	100[d]	See cold-rolled steel for general tone. Most effort placed in converting gas-fired furnaces to fluidized bed and electric furnaces.
	1980	8.0	8.5	62.5	16.0	-	5.0	0	0	100	
	1990	12.0	6.0	59.0	18.0	-	5.0	0	0	100	
	2000	14.0	5.0	54.0	22.0	-	5.0	0	0	100	
	III/1975	7.8	8.8	64.6	15.6	-	5.0	0	0	100	See cold-rolled steel for general tone. Little capital available for conversion to electric or fluidized-bed furnace.
	1980	7.8	8.5	63.1	15.6	-	5.0	0	0	100	
	1990	9.5	7.5	62.0	16.0	-	5.0	0	0	100	
	2000	10.0	7.0	62.0	16.0	-	5.0	0	0	100	
Copper - rolled/wire	I/1975	54.6	22.6	-	22.8	-	-	10.0	40.0	50.0	See cold-rolled steel for general tone. Moderate effort devoted to replacing expensive oil with coal.
	1980	56.0	20.2	-	23.8	-	-	10.0	40.0	50.0	
	1990	60.0	13.2	-	26.8	-	-	20.0	30.0	50.0	
	2000	63.0	9.0	-	28.0	-	-	25.0	25.0	50.0	
	III/1975	54.6	22.6	-	22.8	-	-	10.0	40.0	50.0	Marginal replacement of oil due to limited investment capital and low general interest.
	1980	54.6	22.6	-	22.8	-	-	11.0	39.0	50.0	
	1990	56.0	20.2	-	23.8	-	-	12.0	38.0	50.0	
	2000	57.0	18.2	-	24.8	-	-	15.0	35.0	50.0	
Scrap to copper wire	I/1975	3.5	18.7	52.9	16.1	-	8.8	10.0	40.0	50.0	See cold-rolled steel for general tone. Considerable drive to shift away from expensive petroleum and natural gas -- especially since purchased electricity may become cheaper with nuclear power coming on line.
	1980	3.8	18.4	52.9	16.1	-	8.8	10.0	40.0	50.0	
	1990	7.0	7.6	45.6	31.0	-	8.8	20.0	30.0	50.0	
	2000	10.0	4.6	40.0	36.6	-	8.8	25.0	25.0	50.0	
	III/1975	3.5	18.7	52.9	16.1	-	8.8	10.0	40.0	50.0	See cold-rolled steel for general tone. Little interest and capital funds. Only slight relief obtainable from high petroleum costs by small shift to coal.
	1980	3.8	18.4	52.9	16.1	-	8.8	11.0	39.0	50.0	
	1990	5.0	17.2	52.9	16.1	-	8.8	12.0	38.0	50.0	
	2000	6.0	16.2	52.9	16.1	-	8.8	15.0	35.0	50.0	

Table 27 (Cont'd)

Material	Scenario/Year	Primary and Recycle Material through Refining: Coal	Petroleum	Gas	Purchased Electricity	Hydroelectricity	Other	Semifabrication[b]: Coal	Gas	Purchased Electricity	Rationale
Virgin battery lead	I/1975	29.0	3.3	22.9	35.7	-	9.1	0	0	100[e]	See cold-rolled steel for general tone. Emphasis placed on shift to coal and purchased electricity.
	1980	30.0	2.3	22.9	35.7	-	9.1	0	0	100	
	1990	35.0	1.0	18.0	37.0	-	9.1	0	0	100	
	2000	38.0	1.0	12.0	40.0	-	9.1	0	0	100	
	III/1975	29.0	3.3	22.9	35.7	-	9.1	0	0	100	See cold-rolled steel for general tone. Little shift to coal and purchased electricity to obtain some relief from high nonrenewable fuel costs, but not enough investment capital to make much a dent.
	1980	29.0	3.3	22.9	35.7	-	9.1	0	0	100	
	1990	30.0	2.3	22.9	35.7	-	9.1	0	0	100	
	2000	31.0	1.3	21.9	36.7	-	9.1	0	0	100	
Secondary lead	I/1975	29.2	3.0	28.4	16.4	-	22.9	0	0	100[e]	See cold-rolled steel for general tone and virgin battery lead, Scenario I.
	1980	30.2	2.0	28.4	16.4	-	22.9	0	0	100	
	1990	35.0	1.0	21.4	19.7	-	22.9	0	0	100	
	2000	38.0	1.0	17.0	21.1	-	22.9	0	0	100	
	III/1975	29.2	3.0	28.4	16.4	-	22.9	0	0	100	See cold-rolled steel for general tone and virgin lead, Scenario III.
	1980	29.2	3.0	28.4	16.4	-	22.9	0	0	100	
	1990	30.2	2.1	28.4	16.4	-	22.9	0	0	100	
	2000	31.2	1.1	27.4	17.4	-	22.9	0	0	100	
Zinc	I/1975	50.0	0.3	48.9	-	-	1.0	10.0	40.0	50.0	See cold-rolled steel for general tone. Zinc data are poor. Possibly some shift to purchased electricity but questionable.
	1980	50.0	0.3	48.9	-	-	1.0	10.0	40.0	50.0	
	1990	50.0	0.3	45.0	3.7	-	1.0	20.0	30.0	50.0	
	2000	50.0	0.3	42.0	6.7	-	1.0	25.0	25.0	50.0	
	III/1975	50.0	0.3	48.9	-	-	1.0	10.0	40.0	50.0	See cold-rolled steel for general tone. No change since oil is small and capital funds for gas to electricity conversion is minimal.
	1980	50.0	0.3	48.9	-	-	1.0	11.0	39.0	50.0	
	1990	50.0	0.3	48.9	-	-	1.0	12.0	38.0	50.0	
	2000	50.0	0.3	48.9	-	-	1.0	15.0	35.0	50.0	
Electrolytic nickel	I/1975	22.0	6.6	27.0	44.4	-	-	10.0	40.0	50.0	See cold-rolled steel for general tone. Reference data said to have ±50% accuracy. Most petroleum for transportation and coke. Coal and purchased electricity may be substitutable for natural gas.
	1980	22.0	6.6	27.0	44.4	-	-	10.0	40.0	50.0	
	1990	26.0	6.6	22.4	45.0	-	-	20.0	30.0	50.0	
	2000	28.0	6.6	16.4	49.0	-	-	25.0	25.0	50.0	
	III/1975	22.0	6.6	27.0	44.4	-	-	10.0	40.0	50.0	See cold-rolled steel for general tone. Some shift to coal to avoid high natural gas cost. Lack of investment capital results in little increase in electricity generating capacity.
	1980	22.0	6.6	27.0	44.4	-	-	11.0	39.0	50.0	
	1990	24.0	6.6	25.0	44.4	-	-	12.0	38.0	50.0	
	2000	25.0	6.6	24.0	44.4	-	-	15.0	35.0	50.0	

Table 27 (Cont'd)

Material	Scenario/ Year	Primary and Recycle Material through Refining: Coal	Petro- leum	Gas	Purchased Elec- tricity	Hydro- elec- tricity	Other	Semifabrication[b]: Coal	Gas	Purchased Elec- tricity	Rationale
Recycled nickel	I/1975	20.0	5.0	60.0	15.0	-	-	10.0	40.0	50.0	See cold-rolled steel for general tone. No recycling data available -- gross engineering estimate appears here. Petroleum used for transportation, gas and coal for furnace melting of scrap, and electricity for semifabrication processing. Scenario effort centered on reducing natural gas.
	1980	20.0	5.0	60.0	15.0	-	-	10.0	40.0	50.0	
	1990	28.0	5.0	52.0	15.0	-	-	20.0	30.0	50.0	
	2000	30.0	5.0	49.0	16.0	-	-	25.0	25.0	50.0	
	III/1975	20.0	5.0	60.0	15.0	-	-	10.0	40.0	50.0	See cold-rolled steel for general tone. No change because of grossness of estimate and limited funds in Scenario III.
	1980	20.0	5.0	60.0	15.0	-	-	11.0	39.0	50.0	
	1990	20.0	5.0	60.0	15.0	-	-	12.0	38.0	50.0	
	2000	20.0	5.0	60.0	15.0	-	-	15.0	35.0	50.0	
Glass	I/1975	2.0	17.5	68.0	10.0	-	2.5	-	-	-[f]	See cold-rolled steel for general tone. Projection assumes float glass process where coal and electricity can be substituted for gas flame in maintaining molten metal pool and pot. 1.3% not accounted for by reference.
	1980	2.0	16.5	68.0	11.0	-	2.5	-	-	-	
	1990	5.0	13.5	64.0	15.0	-	2.5	-	-	-	
	2000	10.0	8.5	54.0	25.0	-	2.5	-	-	-	
	III/1975	2.0	17.5	68.0	10.0	-	2.5	-	-	-	See cold-rolled steel for general tone. Lack of investment funds results in little relief from petroleum and natural gas costs.
	1980	2.0	17.5	68.0	10.0	-	2.5	-	-	-	
	1990	2.5	17.0	67.0	11.0	-	2.5	-	-	-	
	2000	3.0	16.5	66.5	11.5	-	2.5	-	-	-	
Sound deadeners	I/1975	0.8	23.8	17.4	15.9	-	42.2	-	-	-	See cold-rolled steel for general tone. Assumed similar to pulp and paper industry. "Other" is process-derived wood and bark chips. In addition to coal and electricity emphasis, some attention will be directed toward making the industry energy-self-sufficient.
	1980	1.8	22.8	17.4	15.9	-	42.2	-	-	-	
	1990	9.8	14.8	12.4	17.9	-	45.1	-	-	-	
	2000	13.8	10.8	10.0	19.0	-	46.4	-	-	-	
	III/1975	0.8	23.8	17.4	15.9	-	42.2	-	-	-	See cold-rolled steel for general tone. Some relief from high petroleum and gas costs but little capital or incentive to make major process changes.
	1980	0.8	23.8	17.4	15.9	-	42.2	-	-	-	
	1990	2.8	21.8	15.4	15.9	-	44.2	-	-	-	
	2000	3.8	20.8	14.4	15.9	-	45.2	-	-	-	

Table 27 (Cont'd)

Material	Scenario/ Year	Primary and Recycle Material through Refining: Coal	Petro- leum	Gas	Purchased Elec- tricity	Hydro- elec- tricity	Other	Semifabrication[b]: Coal	Gas	Purchased Elec- tricity	Rationale
Ceramics	I/1975	21.1	7.0	61.9	10.0	-	-	-	-	-[g]	See cold-rolled steel for general tone. Flame firing is probably the method of choice for reasons of even temperature distribution in flow-through lines. Fluidized bed or other coal conversions substitute for oil and natural gas. Electricity retained for small item kilns.
	1980	26.0	6.0	58.0	10.0	-	-	-	-	-	
	1990	38.0	4.0	48.0	10.0	-	-	-	-	-	
	2000	42.0	3.0	45.0	10.0	-	-	-	-	-	
	III/1975	21.1	7.0	61.9	10.0	-	-	-	-	-	See cold-rolled steel for general tone. Lack of development funds and investment capital slows cost-driven conversion from oil and natural gas to coal. No R&D effort devoted to electric kilns.
	1980	21.1	7.0	61.9	10.0	-	-	-	-	-	
	1990	25.0	6.0	59.0	10.0	-	-	-	-	-	
	2000	30.0	5.0	55.0	10.0	-	-	-	-	-	
Virgin material tires	I/1975	17.5	26.4	35.8	20.3	-	-	-	-	-[g]	See cold-rolled steel for general tone. Most energy is feedstock. Purchased electricity used for molding and curing. Main shift to coal occurs when coal-derived feedstocks become available.
	1980	17.5	26.4	35.8	20.3	-	-	-	-	-	
	1990	20.5	24.9	34.3	20.3	-	-	-	-	-	
	2000	28.5	20.9	30.3	20.3	-	-	-	-	-	
	III/1975	17.5	26.4	35.8	20.3	-	-	-	-	-	See cold-rolled steel for general tone. No change. Lack of interest and investment capital forces status quo.
	1980	17.5	26.4	35.8	20.3	-	-	-	-	-	
	1990	17.5	26.4	35.8	20.3	-	-	-	-	-	
	2000	17.5	26.4	35.8	20.3	-	-	-	-	-	
Scrap to tires	I/1975	1.0	1.5	2.1	95.4	-	-	-	-	-[g]	See cold-rolled steel for general tone. This distribution is an engineering estimate to account for potentially high recycle rates. Some makeup feedstock will be required and will be distributed in same proportion as virgin feedstock. Balance of energy used for molding and curing. Feedstock distribution changes are synchronized with virgin tire changes as a function of scenario.
	1980	1.0	1.5	2.1	95.4	-	-	-	-	-	
	1990	1.4	1.3	1.9	95.4	-	-	-	-	-	
	2000	2.0	1.0	1.6	95.4	-	-	-	-	-	
	III/1975	1.0	1.5	2.1	95.4	-	-	-	-	-	See Scenario I note.
	1980	1.0	1.5	2.1	95.4	-	-	-	-	-	
	1990	1.0	1.5	2.1	95.4	-	-	-	-	-	
	2000	1.0	1.5	2.1	95.4	-	-	-	-	-	

Table 27 (Cont'd)

Material	Scenario/ Year	Primary and Recycle Material through Refining: Coal	Petro- leum	Gas	Purchased Elec- tricity	Hydro- elec- tricity	Other	Semifabrication[b]: Coal	Gas	Purchased Elec- tricity	Rationale
Vehicle fabrication	I/1975	20.4	6.3	52.9	20.4	-	-	NA[h]	NA	NA	See cold-rolled steel for general tone. Main shift to coal for space heating and any in-plant electricity generation. Purchased electricity used for machine tool and line operation. Some petroleum and gas required for material pre-heating.
	1980	22.4	6.3	50.9	20.4	-	-	NA	NA	NA	
	1990	34.4	5.3	39.9	20.4	-	-	NA	NA	NA	
	2000	40.4	4.3	34.9	20.4	-	-	NA	NA	NA	
	III/1975	20.4	6.3	52.9	20.4	-	-	NA	NA	NA	See cold-rolled steel for general tone. Shift to coal markedly reduced because of lack of conversion capital and potentially large imports of foreign vehicles.
	1980	20.4	6.3	52.9	20.4	-	-	NA	NA	NA	
	1990	21.4	6.3	51.9	20.4	-	-	NA	NA	NA	
	2000	25.4	6.3	47.9	20.4	-	-	NA	NA	NA	
Titanium	All All	Neg.	7.4	2.4	66.5	-	24.0	20.0	30.0	50.0	Sparse data. Since petroleum and natural gas percentages are small and "other" is large and undefined, a scenario breakdown is not warranted. No recycling data.
Sodium	All All	9.6	0.4	-	89.0	-	1.0	NA	NA	NA	Little improvement can be projected since most energy is already coal and purchased electricity.
Plastics	All All	Neg.	26.4	66.3	7.2	-	-	-	-	-[f]	Little change possible -- most petroleum and natural gas is feedstock energy.
Virgin rubber	All All	0.1	47.8	53.9	9.7	-	-	-	-	-[f]	Little change possible -- most petroleum and natural gas is feedstock energy. See tires also.
Frasch sulfuric acid	All All	-	-	94.4	0.5	-	5.1	NA	NA	NA	Little change possible if Frasch process used. Natural gas apparently a hydrogen source.
Recovered sulfur	All All	-	-	-	-	-	-	NA	NA	NA	Exothermic reaction.
Paints	All All	22.6	17.8	38.7	20.9	-	-	-	-	-[f]	Too little known about process to make reasonable projection.
Carbon graphite	All All	-	19.6	39.6	40.6	-	-	-	-	-[f]	Too little known about process to make reasonable projection.

[a]Fuel distribution percentages may not add to 100% because of rounding.

[b]No data available -- engineering estimate.

[c]Semifabrication as cast.

[d]Investment casting - mold heating.

[e]Mold heating and material processing.

[f]Assumed included in basic distribution.

[g]Included in basic distribution.

[h]NA = Not applicable.

Table 28 TAPCUT Fuel Distributions
(% of National Totals)

Energy and Sources	1975	1980	Scenario I 1990	Scenario I 2000	Scenario III 1990	Scenario III 2000
Electricity Generation Only						
Coal (direct-fired)	46	46	55	43	54	56
Nuclear	12	12	23	36	19	25
Oil	17	17	3	3	4	3
Natural gas	14	14	4	2	10	1
New fuels						
Coal gas	–	–	2	5	–	–
Coal liquids	–	–	1	–	–	–
Oil shale	–	–	–	–	–	–
Other						
Hydroelectricity	11	11	8	7	11	10
Geothermal	–	–	–	–	–	1
Wind	–	–	2	2	2	4
Solar	–	–	2	2	–	–
U.S. Energy Sources						
Electricity (incl. losses)	30	30	30.2	30.2	30.2	30.3
Other	70	70	69.8	69.8	69.8	69.7
All Fuel Uses						
Imported oil	18	22	11	3	18	15
Domestic oil	27	25	18	20	24	21
Coal (direct-fired)	19	20	26	22	23	30
Nuclear	3	3.5	7	11	6	7
Renewables	4	4	7	10	6	8
Other	0.4	0.5	–	–	–	–
Natural gas	28	25	24	21	23	19
Coal liquids	–	–	2	3	0	0
Coal gas	–	–	1	3	0	0
Oil shale	–	–	4	7	0	0

Table 29 Energy per Pound of Material by Energy Type, Material, Year, and Scenario (Btu/lb material)

Material and Year	Scenario	Energy Type: Coal	Petroleum	Natural Gas	Purchased Elec-tricity	Other	Total
Cold-Rolled Steel							
1980	I	8,301	772	3,186	6,165	-	18,424
	III	8,321	777	3,241	6,183	-	18,522
1990	I	5,852	571	2,614	4,826	-	13,863
	III	7,919	733	2,992	5,809	-	17,453
2000	I	5,567	551	2,589	4,822	-	13,529
	III	7,741	702	2,727	5,204	-	16,374
Stainless Steel							
1980	I	14,598	1,286	4,640	8,317	-	28,841
	III	15,375	1,355	4,889	8,390	-	30,009
1990	I	11,284	1,005	3,737	7,290	-	23,316
	III	13,611	1,186	4,153	7,081	-	26,031
2000	I	10,751	964	3,651	7,270	-	22,636
	III	12,147	1,059	3,705	6,294	-	23,205
Cast Iron							
1980	I	5,326	444	2,067	811	199	8,847
	III	5,417	452	2,105	827	203	9,004
1990	I	5,078	210	1,622	821	198	7,929
	III	5,206	338	1,734	715	163	8,156
2000	I	5,157	148	1,209	935	202	7,651
	III	5,110	306	1,325	607	117	7,465

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Electricity	Other	Total
		Energy Type					
Nodular Iron							
1980	I	7,345	612	2,907	1,157	294	12,315
	III	7,480	623	2,963	1,180	300	12,546
1990	I	6,980	290	2,282	1,175	293	11,030
	III	7,181	467	2,435	1,018	241	11,342
2000	I	7,086	205	1,703	1,338	299	10,631
	III	7,014	420	1,851	858	173	10,316
Malleable Iron							
1980	I	8,144	678	3,239	1,294	332	13,687
	III	8,296	691	3,302	1,320	339	13,948
1990	I	7,734	322	2,544	1,316	330	12,246
	III	7,963	517	2,713	1,138	272	12,603
2000	I	7,849	228	1,899	1,498	337	11,811
	III	7,768	465	2,059	958	195	11,445
Copper							
1980	I	21,266	7,321	4,857	14,408	35	47,887
	III	20,951	8,196	4,958	14,314	37	48,456
1990	I	21,610	4,288	3,733	14,542	56	44,229
	III	17,789	6,033	4,033	12,155	31	40,041
2000	I	23,745	3,010	3,166	15,241	70	45,232
	III	18,388	5,441	3,729	12,451	31	40,040
Aluminum							
1980	I	1,700	2,138	26,380	33,837	11,010[a]	75,065
	III	2,251	2,824	35,648	41,000	15,543[a]	97,266
1990	I	2,900	1,477	20,346	30,212	7,767[a]	62,702
	III	2,558	1,909	30,716	38,258	11,529[a]	84,970
2000	I	3,847	1,141	17,505	30,341	5,860[a]	58,694
	III	2,971	1,682	28,780	36,937	10,361[a]	80,731

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Elec-tricity	Other	Total
Lead							
1980	I	2,545	187	2,086	5,621	1,139	11,578
	III	2,461	271	2,086	5,621	1,139	11,578
1990	I	2,624	75	1,432	5,000	1,018	10,149
	III	2,561	182	1,793	5,568	1,101	11,205
2000	I	2,849	75	1,021	5,186	1,018	10,149
	III	2,492	100	1,890	5,283	1,062	10,827
Zinc							
1980	I	8,551	42	13,276	8,175	138	30,182
	III	8,715	42	13,113	8,175	138	30,183
1990	I	9,018	36	9,926	7,983	120	27,083
	III	7,857	37	11,300	6,930	124	26,248
2000	I	9,899	37	8,926	8,447	122	27,431
	III	8,186	36	10,863	7,088	121	26,294
Nickel							
1980	I	2,477	363	7,174	7,937	-	17,951
	III	2,596	363	7,056	7,937	-	17,952
1990	I	4,032	348	5,942	7,672	-	17,994
	III	2,441	283	6,314	7,212	-	16,250
2000	I	4,798	341	5,310	7,686	-	18,135
	III	2,831	285	6,016	7,253	-	16,385
Titanium							
1980	I	1,900	12,062	6,937	117,487	40,871	179,797
	III	1,900	12,062	6,937	117,487	40,871	179,797
1990	I	1,785	10,712	6,152	100,288	34,740	153,677
	III	1,710	11,342	6,243	105,738	36,784	161,817
2000	I	1,760	9,551	5,738	89,842	30,976	137,867
	III	1,652	10,530	5,894	98,332	34,151	150,559

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Elec- tricity	Other	Total
		Energy Type					
Tires							
1980	I	6,956	10,494	14,232	11,045	-	42,727
	III	7,036	10,615	14,396	11,138	-	43,185
1990	I	7,503	9,098	12,536	11,148	-	40,285
	III	5,565	8,394	11,385	8,890	-	34,324
2000	I	9,910	7,248	10,514	11,057	-	38,729
	III	5,592	8,436	11,442	9,194	-	34,664
Lithium Sulfide			Distribution Not Determined				
1980	I						63,000
	III						63,000
1990	I						56,700
	III						60,480
2000	I						53,550
	III						57,960
Lithium Chloride			Distribution Not Determined				
1980	I						36,400
	III						36,400
1990	I						32,760
	III						34,940
2000	I						30,940
	III						33,490

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Elec-tricity	Other	Total
		Energy Type					
Potassium Hydroxide/ Potassium Chloride		Distribution Not Determined					
1980	I						4,590
	III						4,590
1990	I						4,330
	III						4,470
2000	I						4,210
	III						4,400
Silicon		Distribution Not Determined					
1980	I						46,850
	III						48,070
1990	I						41,900
	III						45,600
2000	I						39,500
	III						44,370
Sulfur		Distribution Not Determined					
	All						443
Carbon/ Graphite							
	All	-	196	396	406	-	1,000
Ceramics							
1980	I	10,400	2,400	23,200	4,000	-	40,000
	III	8,440	2,800	24,760	4,000	-	40,000
1990	I	15,200	1,600	19,200	4,000	-	40,000
	III	10,000	2,400	23,600	4,000	-	40,000
2000	I	16,800	1,200	18,000	4,000	-	40,000
	III	12,000	2,000	22,000	4,000	-	40,000

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Electricity	Other	Total
		Energy Type					
Glass							
1980	I	196	1,617	6,664	1,078	245	9,800
	III	196	1,715	6,664	980	245	9,800
1990	I	465	1,256	5,952	1,395	233	9,301
	III	241	1,637	6,452	1,059	241	9,630
2000	I	900	765	4,860	2,250	225	9,000
	III	285	1,568	6,318	1,093	238	9,502
Sound Deadeners							
1980	I	126	1,596	1,218	1,113	2,954	7,007
	III	56	1,666	1,218	1,113	2,954	7,007
1990	I	637	962	806	1,164	2,932	6,501
	III	191	1,485	1,049	1,083	3,010	6,818
2000	I	897	702	650	1,235	3,016	6,500
	III	255	1,398	968	1,068	3,037	6,726
Lithium			Distribution Not Determined				
1980	I						197,800
	III						197,800
1990	I						178,000
	III						189,890
2000	I						168,150
	III						181,970
Cobalt							
1980	I	16,240	5,858	–	6,902	–	29,000
	III	15,823	6,549	–	6,607	–	28,979
1990	I	15,570	3,425	–	6,955	–	25,950
	III	14,750	5,321	–	6,269	–	26,340
2000	I	15,372	2,196	–	6,832	–	24,400
	III	15,014	4,794	–	6,532	–	26,340

Table 29 (Cont'd)

Material and Year	Scenario	Coal	Petroleum	Natural Gas	Purchased Elec- tricity	Other	Total
Plastics							
1980	I	-	13,116	32,938	3,577	-	49,631
	III	-	13,607	34,171	3,711	-	51,489
1990	I	-	12,735	31,983	3,473	-	48,191
	III	-	13,274	33,336	3,620	-	50,230
2000	I	-	12,704	31,904	3,465	-	48,073
	III	-	13,464	33,813	3,672	-	50,949
Sodium							
1980	I	4,416	184	-	40,940	460	46,000
	III	4,416	184	-	40,940	460	46,000
1990	I	4,032	168	-	37,380	420	42,000
	III	4,239	177	-	39,302	442	44,160
2000	I	3,974	166	-	36,846	414	41,400
	III	4,063	169	-	37,665	423	42,320
Paint							
1980	I	1,582	1,246	2,709	1,463	-	7,000
	III	1,582	1,246	2,709	1,463	-	7,000
1990	I	1,469	1,157	2,516	1,359	-	6,501
	III	1,539	1,212	2,635	1,423	-	6,809
2000	I	1,469	1,157	2,516	1,359	-	6,501
	III	1,519	1,196	2,601	1,409	-	6,720
Sulfuric Acid							
	All	-	-	19	Neg.	1	20
Zinc Chloride							
	All	Distribution Not Determined					18,600
Magnesium							
	All	-	537	65,156	100,061	13,246	179,000

Table 29 (Cont'd)

Material and Year	Scenario	Energy Type: Coal	Petroleum	Natural Gas	Purchased Electricity	Other	Total
Vehicle Fabrication[b]							
1980	I	1,478	416	3,359	1,346	-	6,600
	III	1,383	427	3,587	1,383		6,780
1990	I	2,167	334	2,514	1,285	-	6,300
	III	1,408	415	3,415	1,342	-	6,580
2000	I	2,505	267	2,164	1,265	-	6,200
	III	1,643	408	3,099	1,320	-	6,470

[a]Largely hydroelectricity.

[b]Energy for vehicle fabrication is per pound of vehicle.

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